

The logo for ARLAB, featuring the letters "ARLAB" in a bold, red, sans-serif font.

ME/CprE/ComS 557

Computer Graphics and Geometric Modeling

Transformation and Viewing

September 15, 2015

Rafael Radkowski

The Iowa State University logo, featuring the words "IOWA STATE UNIVERSITY" in a large, red, serif font, with "OF SCIENCE AND TECHNOLOGY" in a smaller, green, serif font below it.

Topics

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- Homogenous Space
- Transformation of 3D models
- Viewing in 3D
- Transformations in OpenGL

Goals of this class:

- Understanding the transformation processes in Computer Graphics
- Transform 3D models in 3D space
- Create and move a virtual camera in 3D space

Homogenous Space

Affine Transformations

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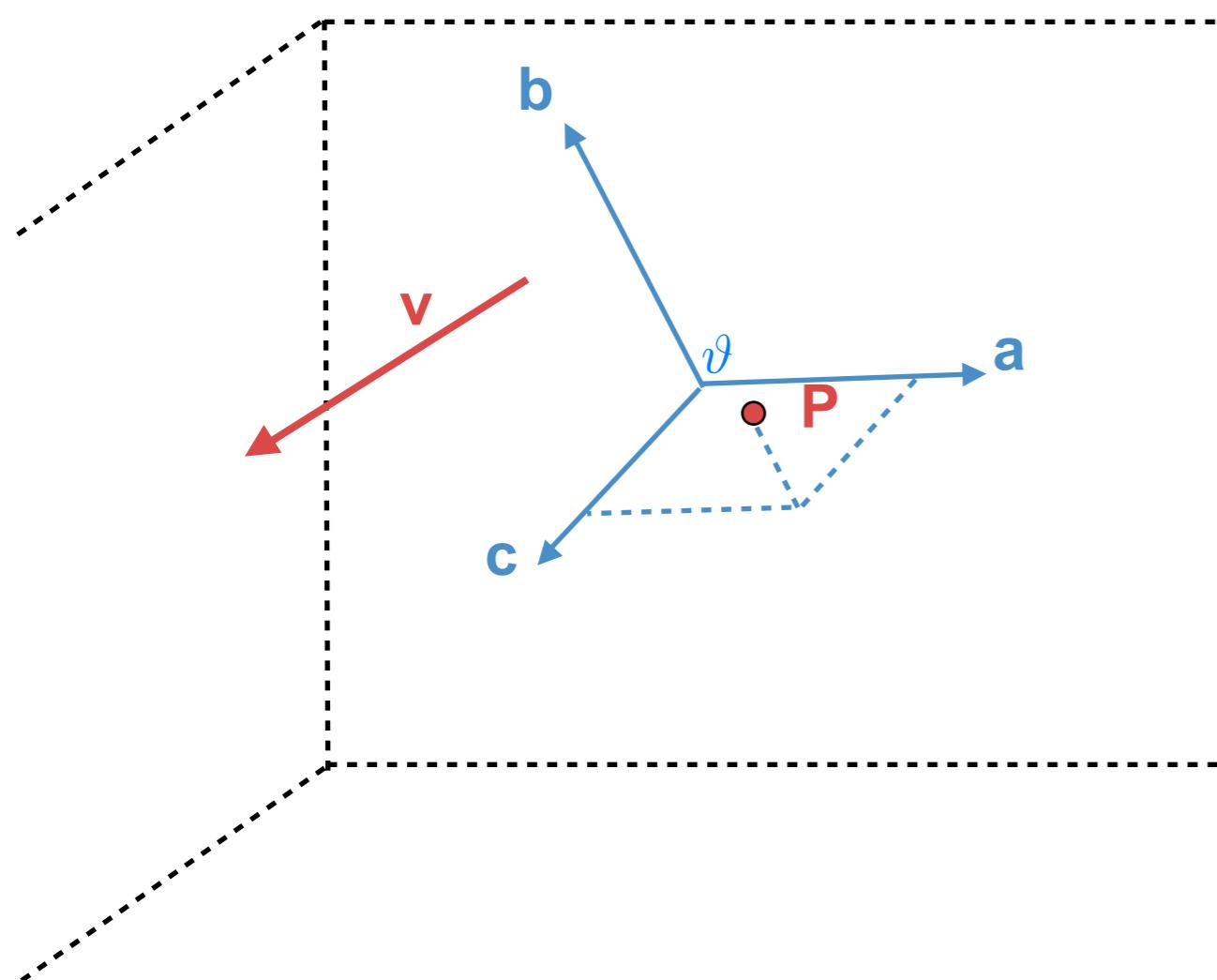
- Affine transformations are all mathematical transformations that preserve the geometrical structure of objects (point remains a point, a line a line, etc.)
- Cornerstone of computer graphics
- Lead to disasters and bugs because points and vectors are not the same!
- A point P has only a location, but no size and direction.
- A vector \mathbf{v} has a direction and a size, but it has no location.

$$P = \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad \mathbf{v} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

- Problems occur when points and vectors are transformed between coordinate systems

Coordinate Systems and Coordinate Frames

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ϑ : origin of the coordinate frame

$\mathbf{a}, \mathbf{b}, \mathbf{c}$: coordinate frame vectors

\mathbf{v} : vector

P : point in coordinate frame

a coordinate frame consists of an origin ϑ and three mutually perpendicular vectors $\mathbf{a}, \mathbf{b}, \mathbf{c}$.

A vector in this coordinate frame is defined as:

$$\mathbf{v} = v_1 \mathbf{a} + v_2 \mathbf{b} + v_3 \mathbf{c}$$

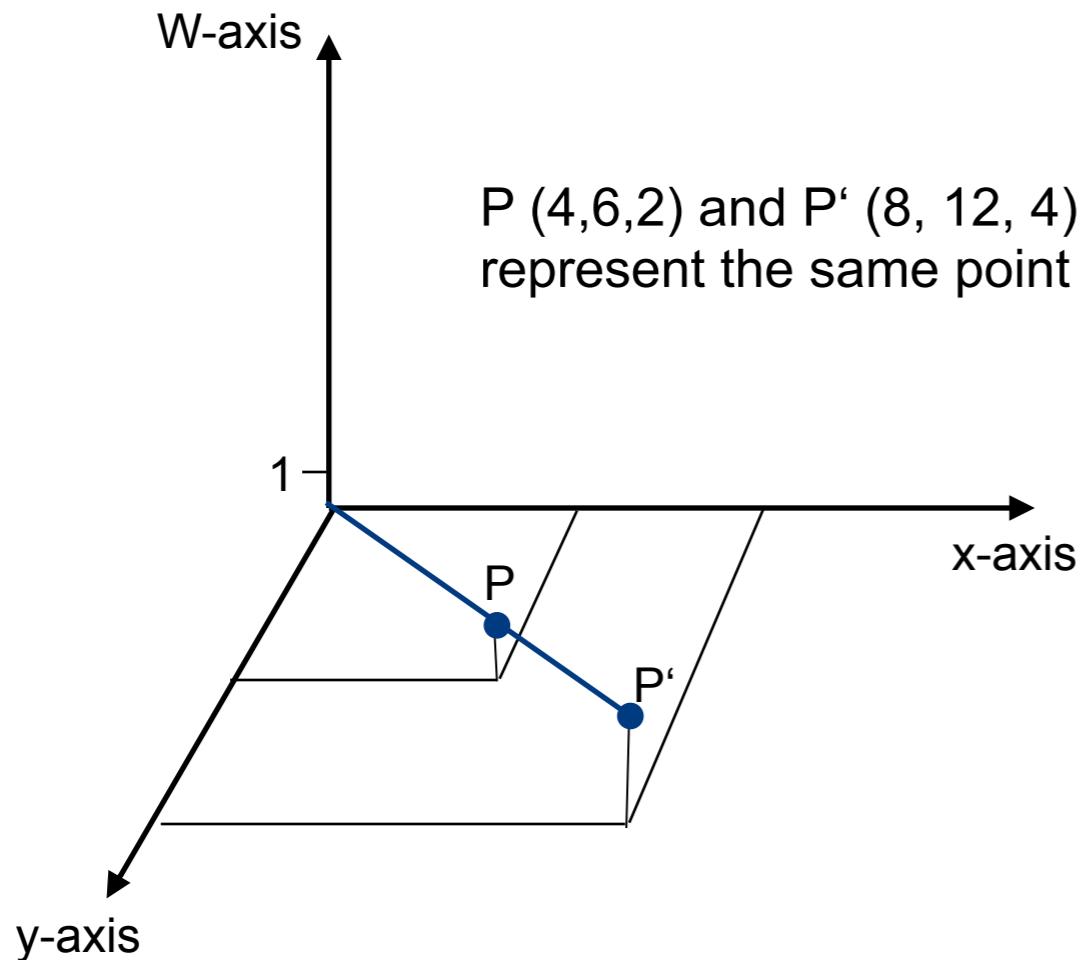
A point in this coordinate systems is defined as:

$$P = \vartheta + p_1 \mathbf{a} + p_2 \mathbf{b} + p_3 \mathbf{c}$$

The basic idea is to make the origin of each coordinate system explicit.

Homogenous Coordinate System - Projective Transformation

ARLAB



P (4,6,2) and P' (8, 12, 4)
represent the same point

The homogeneous coordinate system or projective transformation or projective space is a geometric coordinate system to represent projective information. The advantage is that the coordinates of points and vectors can be represented using a unique matrix. A scaling parameter w

$$H(x, y, z) = \left(\frac{x}{w}, \frac{y}{w}, \frac{z}{w}, 1 \right)$$

which also allows to distinguish points from vectors

- if $w = 0$: the matrix is a vector
- if $w = 1$: the matrix is a point

Same matrix for every transformation,
here, in 2D space

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} m_{0,0} & m_{0,1} & m_{0,2} \\ m_{1,0} & m_{1,1} & m_{1,2} \\ m_{2,0} & m_{2,1} & w \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Transformation of homogenous
coordinates in cartesian coordinates

$$\begin{bmatrix} x_k \\ y_k \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{x_h}{W} \\ \frac{y_h}{W} \\ 1 \end{bmatrix}$$

Homogenous Coordinate System - Projective Transformation

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The homogenous representation of a vector and a point use the same set of underlying attributes a , b , c , and ϑ .

For a vector:

$$\mathbf{v} = (\mathbf{a}, \mathbf{b}, \mathbf{c}, \vartheta) \begin{pmatrix} v_1 \\ v_2 \\ v_3 \\ 0 \end{pmatrix}$$

$$\mathbf{v} = \begin{pmatrix} a_1 & b_1 & c_1 & \vartheta_1 \\ a_2 & b_2 & c_2 & \vartheta_2 \\ a_3 & b_3 & c_3 & \vartheta_3 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ v_3 \\ 0 \end{pmatrix}$$

For a point:

$$P = (\mathbf{a}, \mathbf{b}, \mathbf{c}, \vartheta) \begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ 1 \end{pmatrix}$$

$$P = \begin{pmatrix} a_1 & b_1 & c_1 & \vartheta_1 \\ a_2 & b_2 & c_2 & \vartheta_2 \\ a_3 & b_3 & c_3 & \vartheta_3 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ 1 \end{pmatrix}$$

- A 0 and 1 are used to distinguish a vector and a point
- Same notation for different representation of points and vectors
- Simplifies the maths.

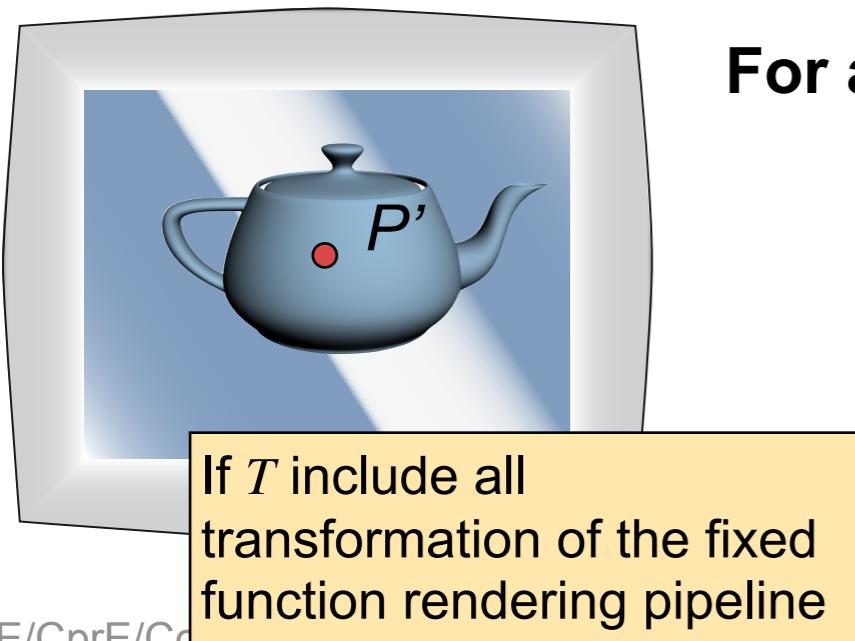
Transformation in 3D

The Homogenous Matrix

The homogenous matrix is used in computer graphics to transform objects in 3D space. It is a 4×4 matrix, which elements represent translations, rotations, and the scale factor of an object.

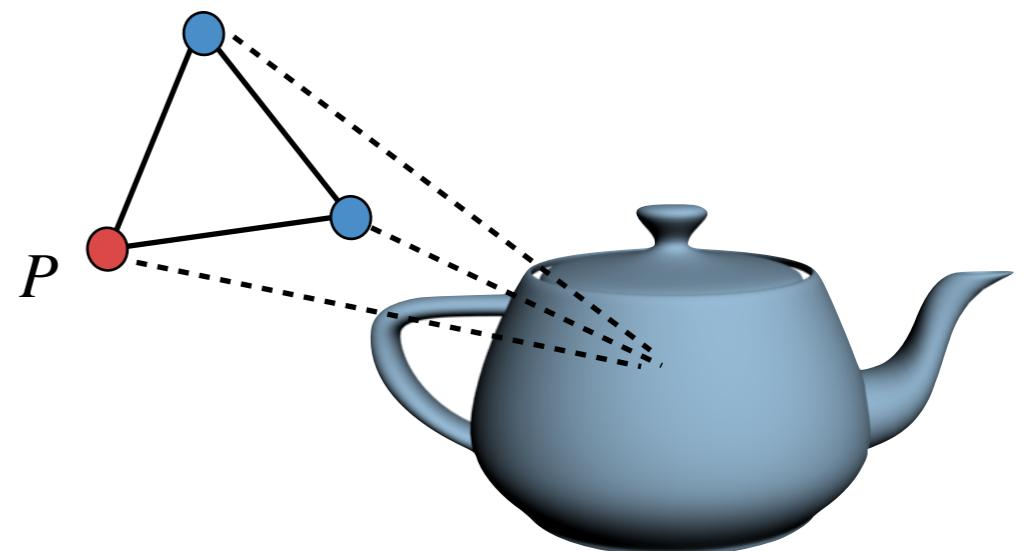
$$T := \begin{bmatrix} \text{Scale} & \text{Rotation} & \text{Translation} \\ r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix}$$

with $r_{44} = w$



For all transformations:

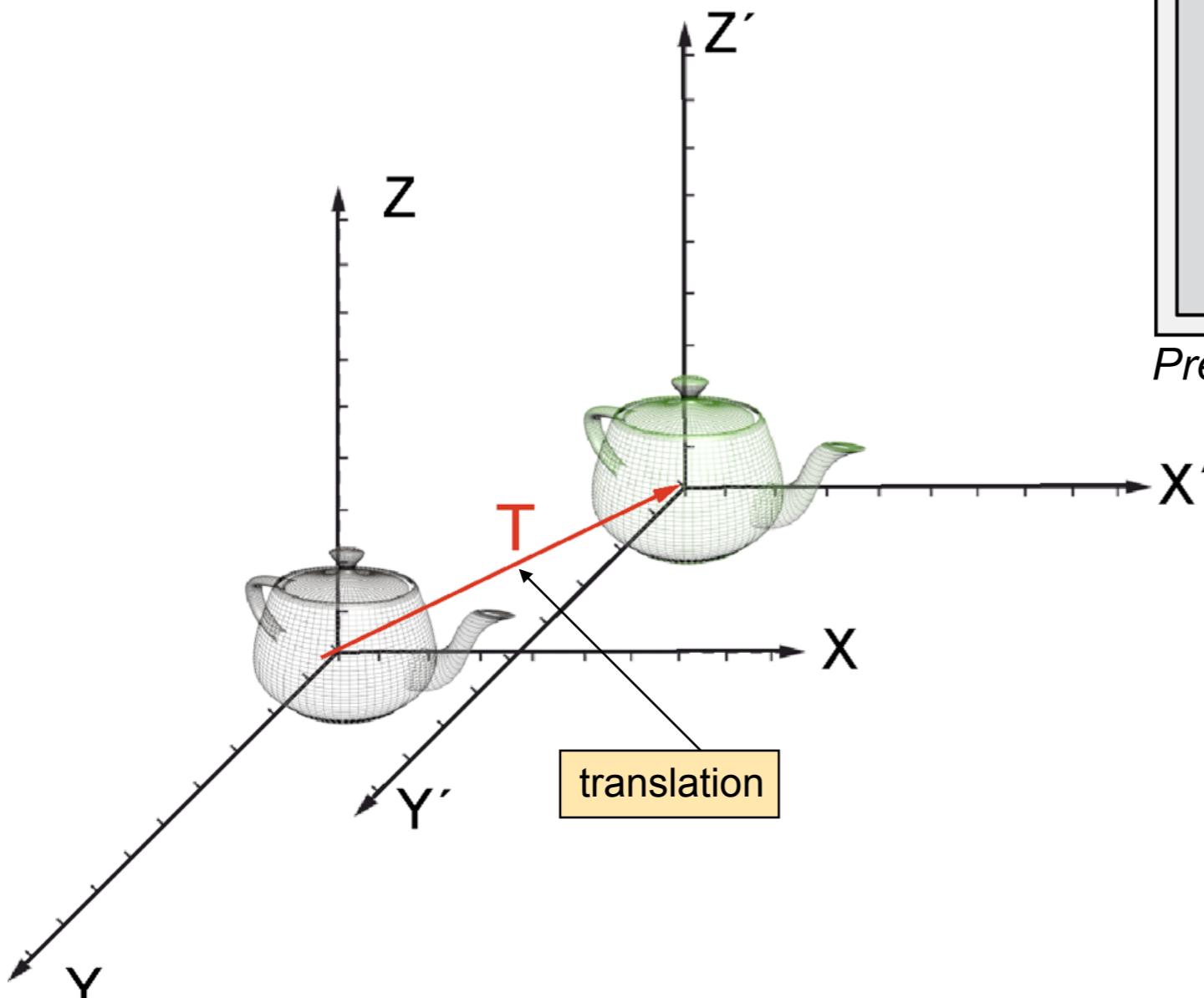
$$P' = T \cdot P$$



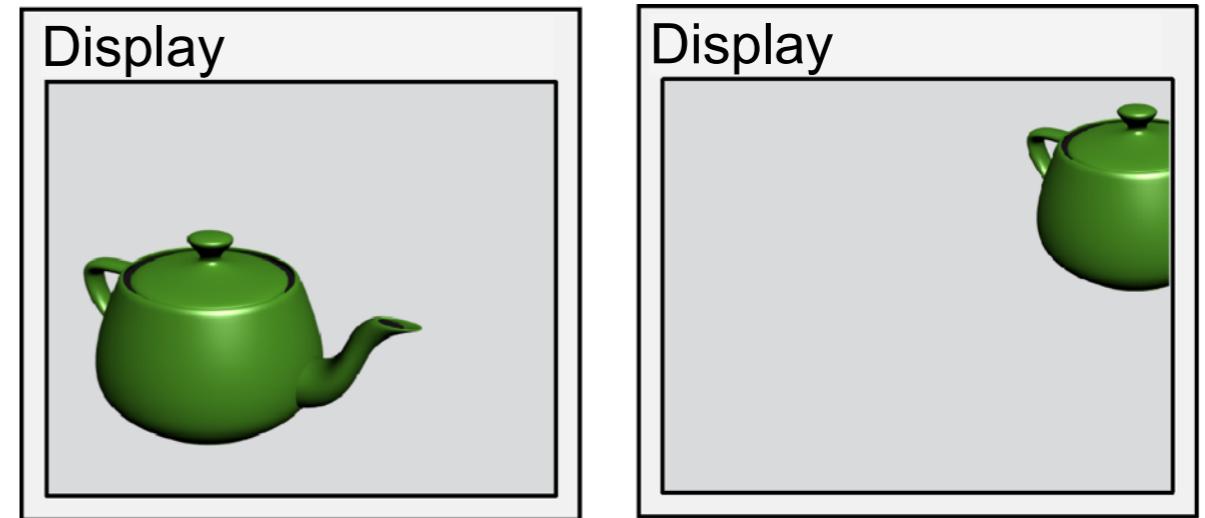
3D-Transformation

Translation

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Translation of a 3D object in 3D space



Presentation of a translated model on screen

Translation of a point $P(x, y, z)$ by T

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

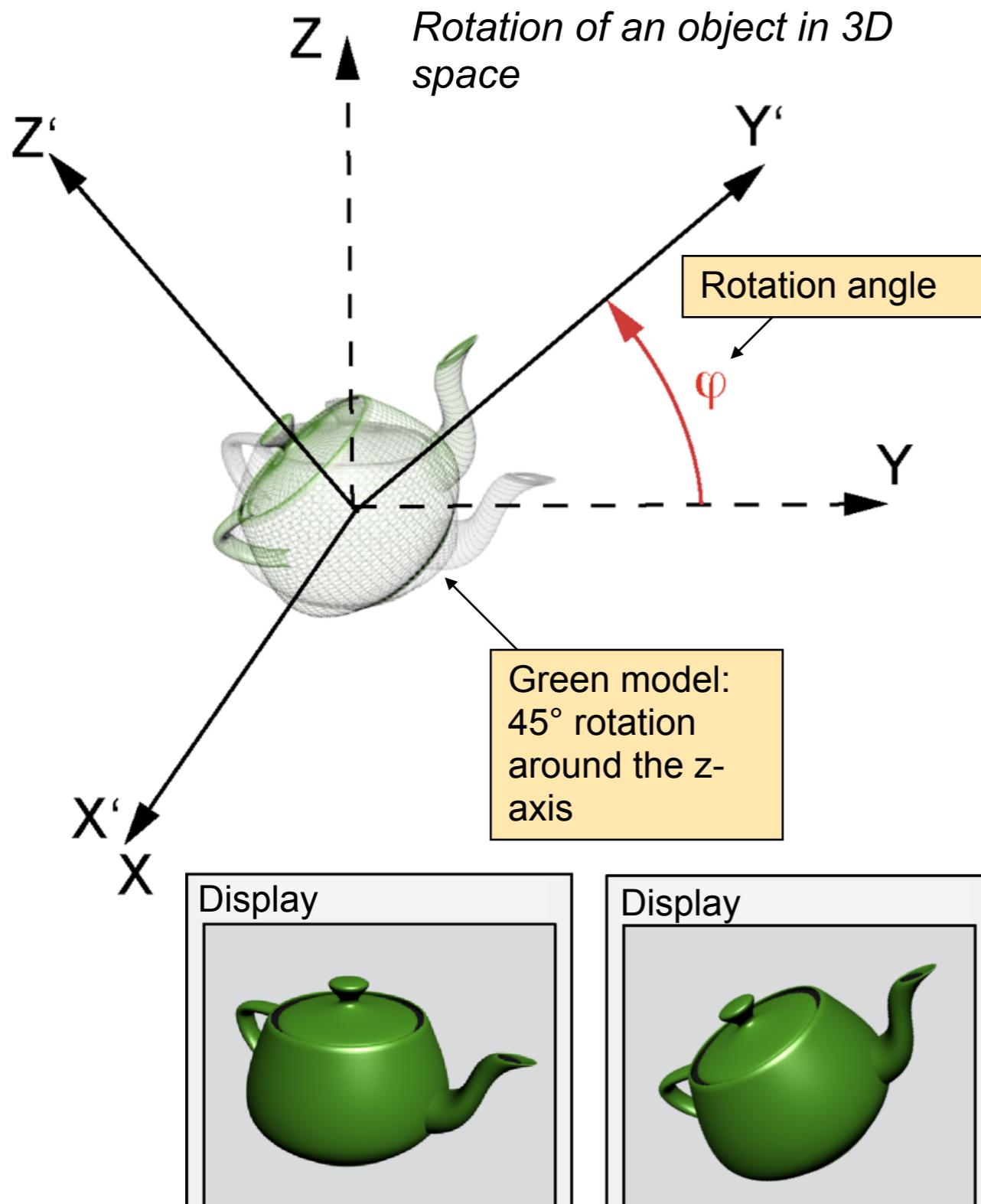
$$P' = T(t_x, t_y, t_z) \cdot P \quad \text{with}$$

$$T(t_x, t_y, t_z) = \begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3D-Transformation

Rotation

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Presentation of a rotated model on screen

Rotation around the x-axis

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\varphi) & -\sin(\varphi) & 0 \\ 0 & \sin(\varphi) & \cos(\varphi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$P' = R_x(\varphi) \cdot P$$

Rotation around the y-axis

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\varphi) & 0 & \sin(\varphi) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\varphi) & 0 & \cos(\varphi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$P' = R_y(\varphi) \cdot P$$

Rotation around the z-axis

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\varphi) & -\sin(\varphi) & 0 & 0 \\ \sin(\varphi) & \cos(\varphi) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

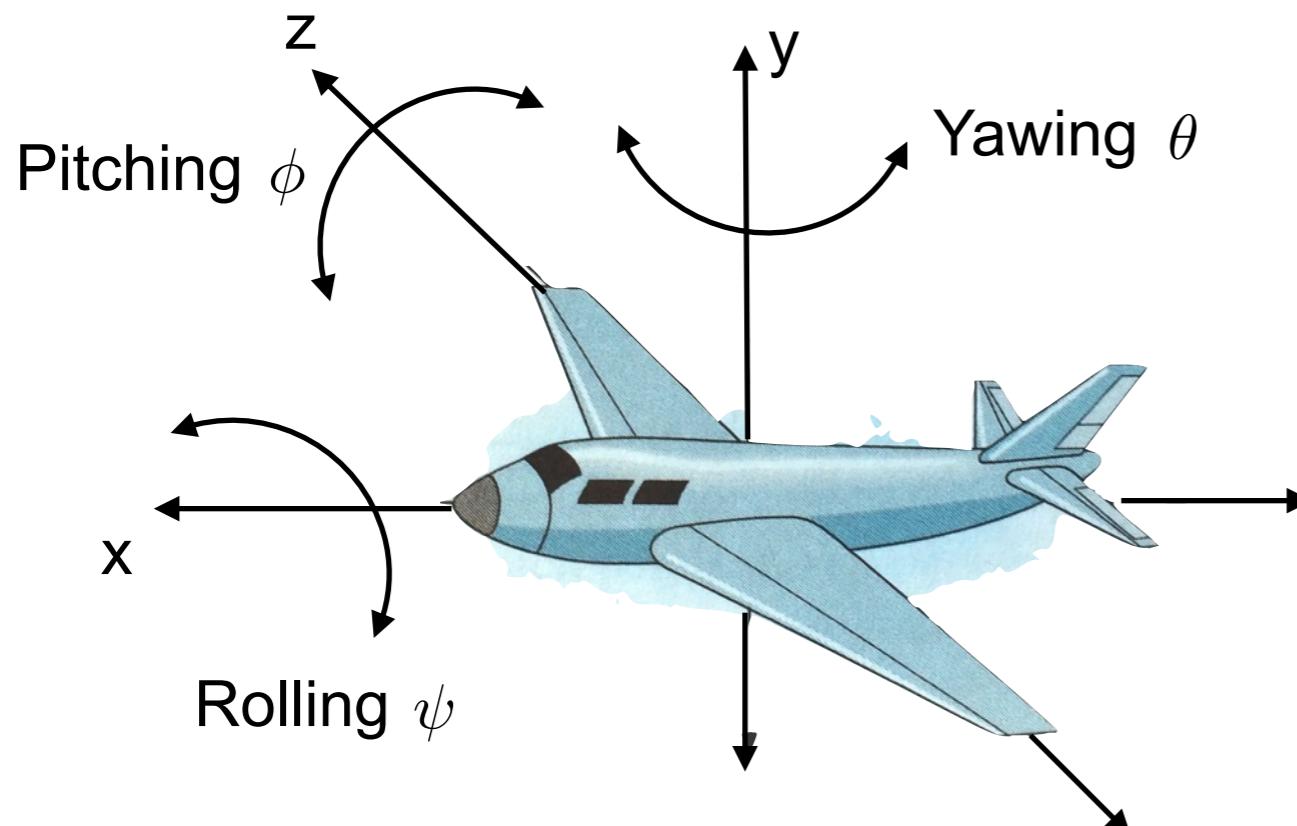
$$P' = R_z(\varphi) \cdot P$$

3D-Transformation

Euler Angles

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Euler angles are a mechanism for creating a rotation through the sequence of three simple rotations:



$$\mathbf{M} = R_{yz}(\psi) \ R_{zx}(\theta) \ R_{xy}(\phi)$$

$$\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \psi & -\sin \psi \\ 0 & \sin \psi & \cos \psi \end{bmatrix} \begin{bmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{bmatrix} \begin{bmatrix} \cos \phi & -\sin \phi & 0 \\ \sin \phi & \cos \phi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

3D-Transformation

Euler Angles

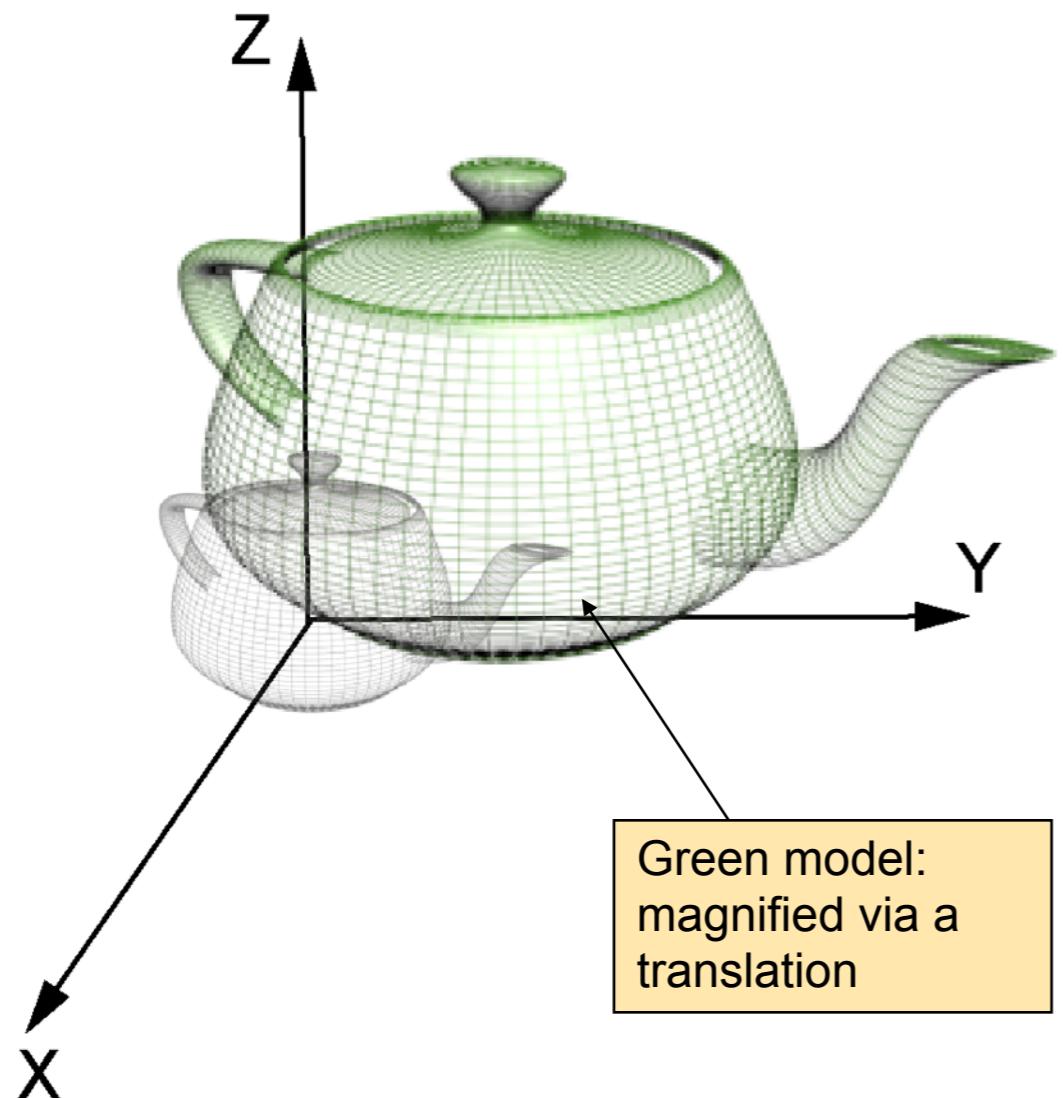
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In homogenous coordinate system:

$$\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos \psi & -\sin \psi & 0 \\ 0 & \sin \psi & \cos \psi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \theta & 0 & \sin \theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \theta & 0 & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \phi & -\sin \phi & 0 & 0 \\ \sin \phi & \cos \phi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

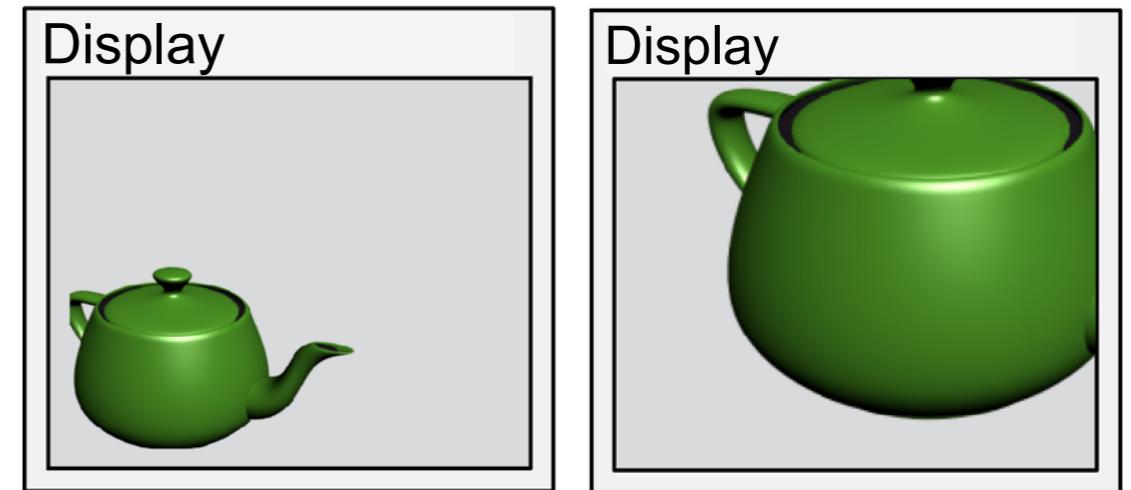
3D-Transformation

Scaling



Scale of an object in 3D space

Every scaling incorporates a translation, if the 3D model is not at coordinate system origin.



Presentation of a scaled model on screen

Scaling of a point $P(x, y, z)$ by the scaling factor S

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$P' = S(s_x, s_y, s_z) \cdot P \quad \text{with}$$

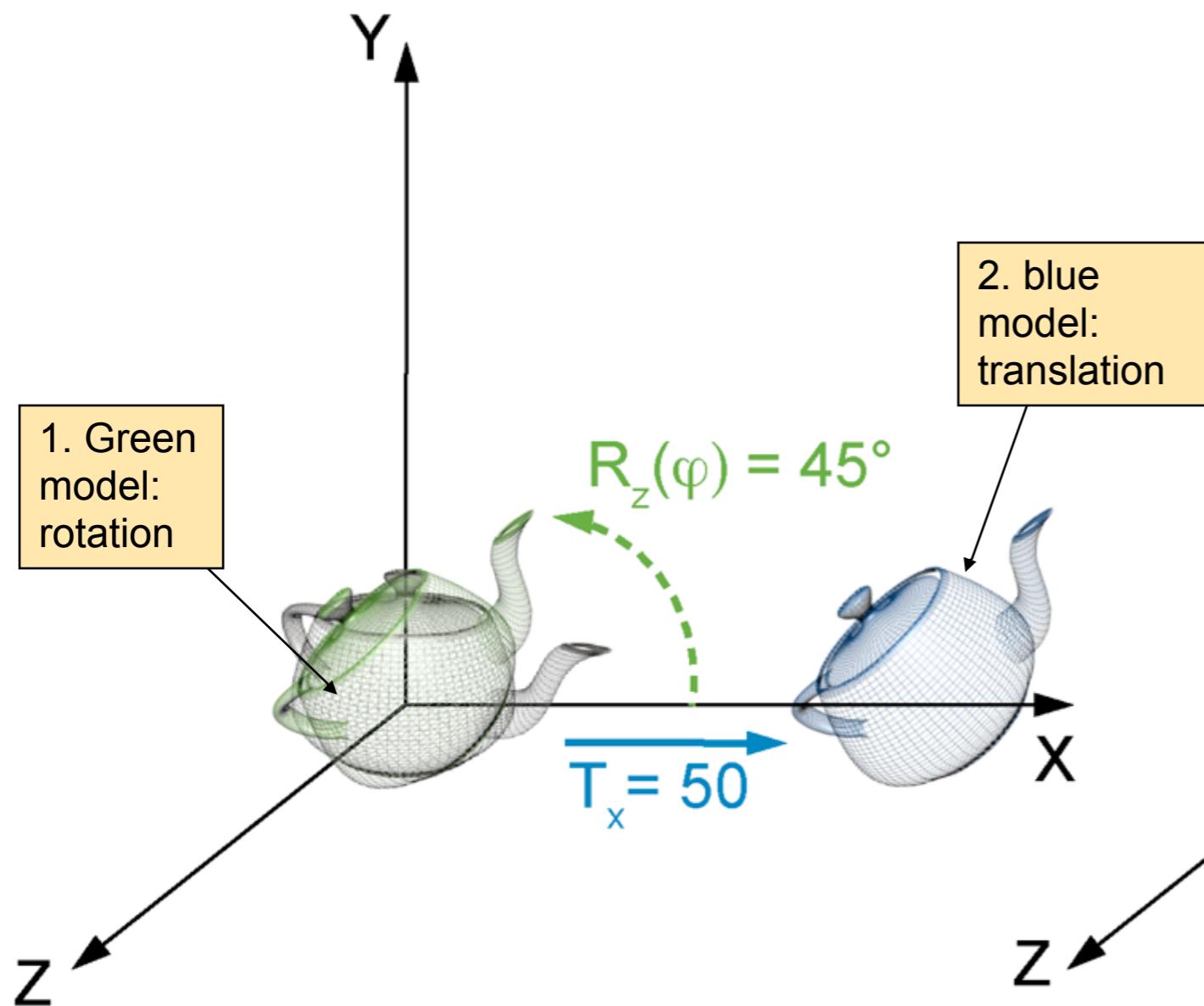
$$S(s_x, s_y, s_z) = \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sequence of Transformation

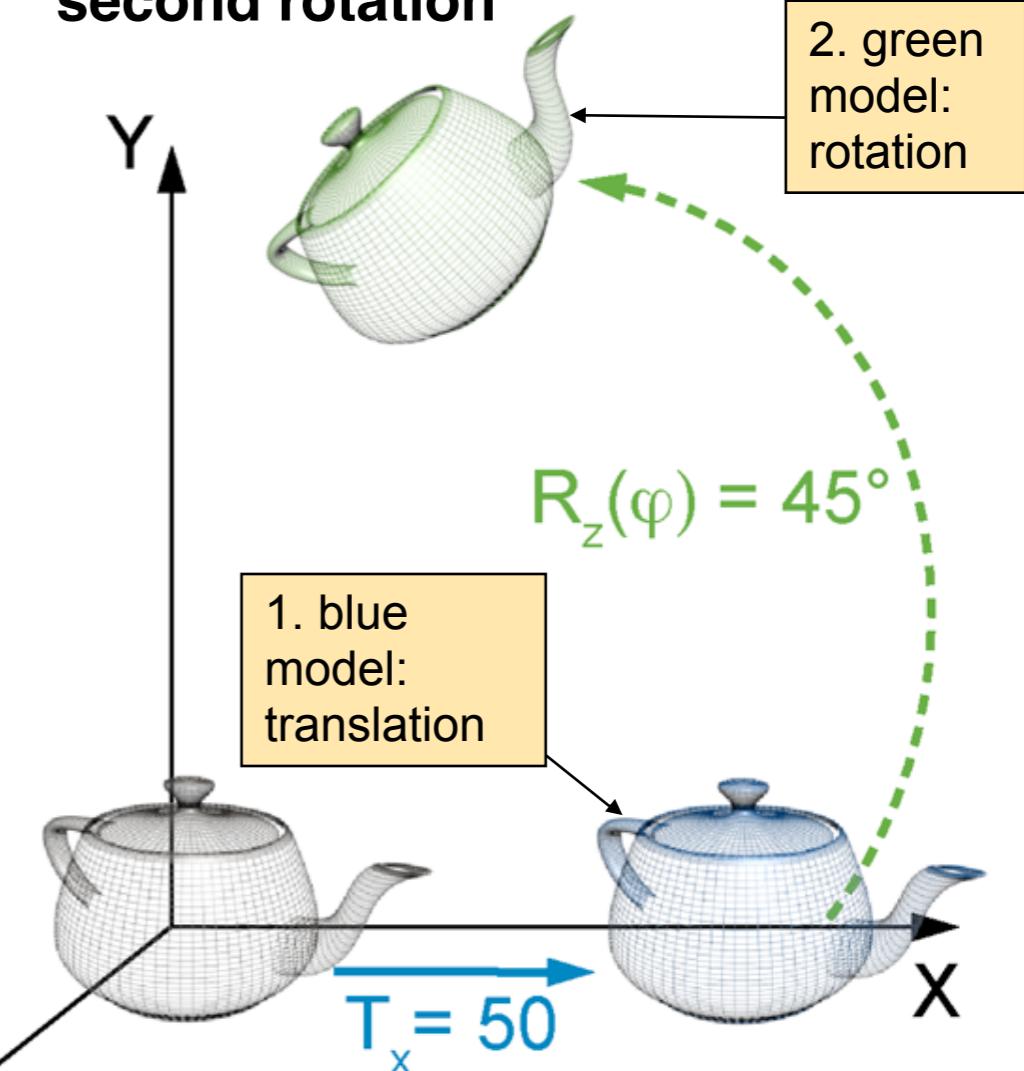
World Coordinates

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First rotation,
second translation



First translation,
second rotation

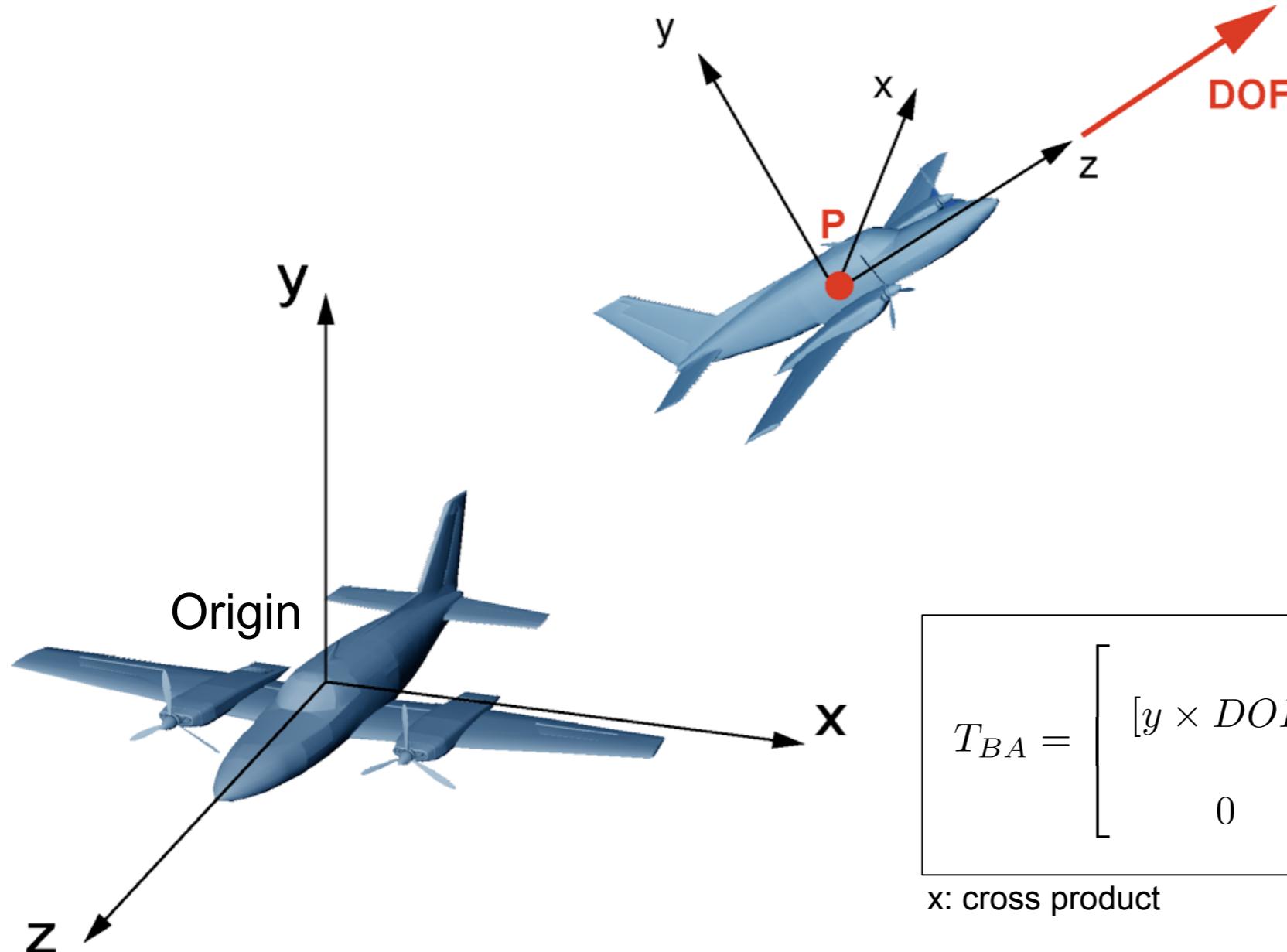


The final output and the sequence of transformation depends on the sequence of matrix multiplications:

$$P' = T_x \cdot R_z \cdot P \quad \text{vs.} \quad P' = R_z \cdot T_x \cdot P$$

Transformation of Coordinate Systems

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$$T_{BA} = \begin{bmatrix} [y \times DOF] & |DOF \times [y \times DOF]| & |DOF| & P_x \\ 0 & 0 & 0 & P_y \\ 0 & 0 & 1 & P_z \end{bmatrix}$$

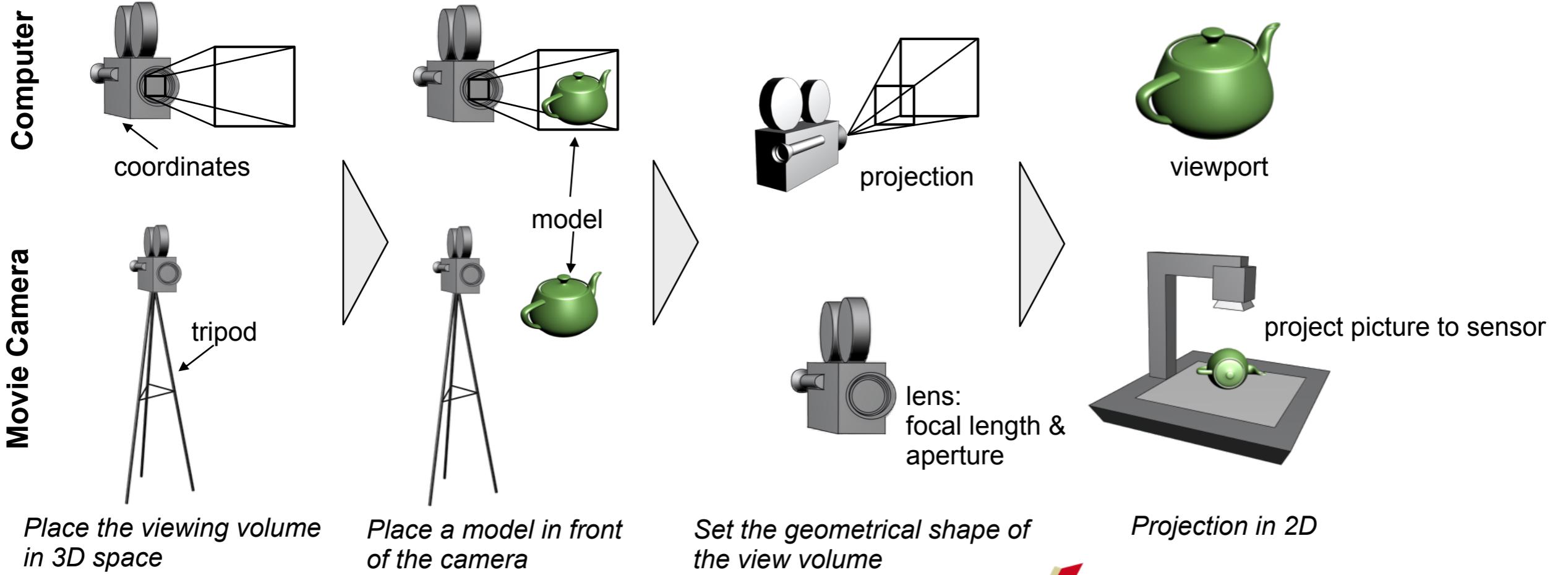
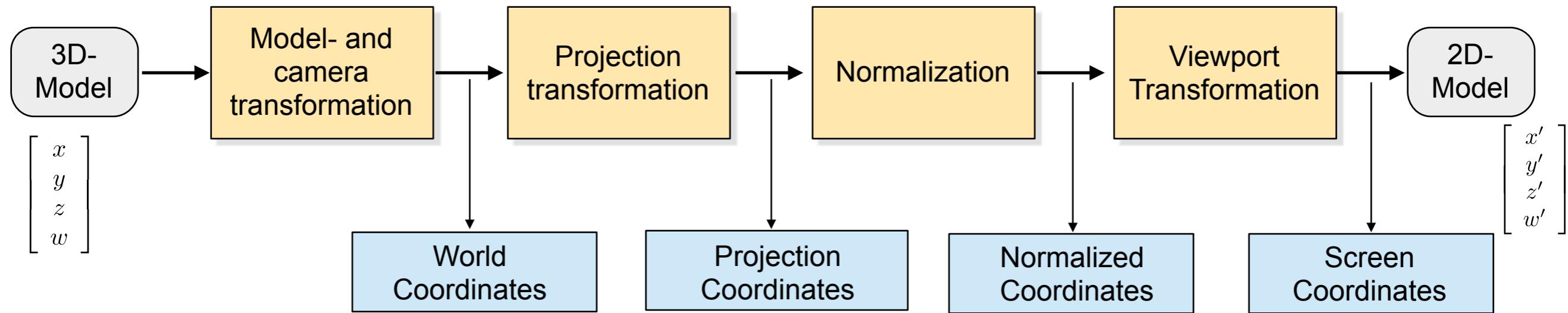
x: cross product

*Translation of a airplane to the point P with alignment DOF
(DOF.: Direction of Flight)*

Viewing in OpenGL

Viewing in 3D

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Place the viewing volume in 3D space

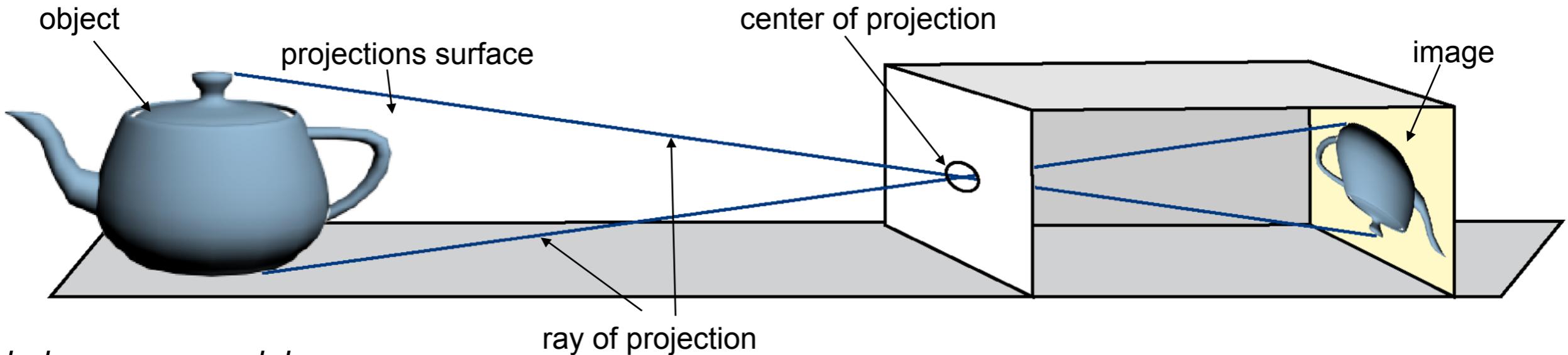
Place a model in front of the camera

Set the geometrical shape of the view volume

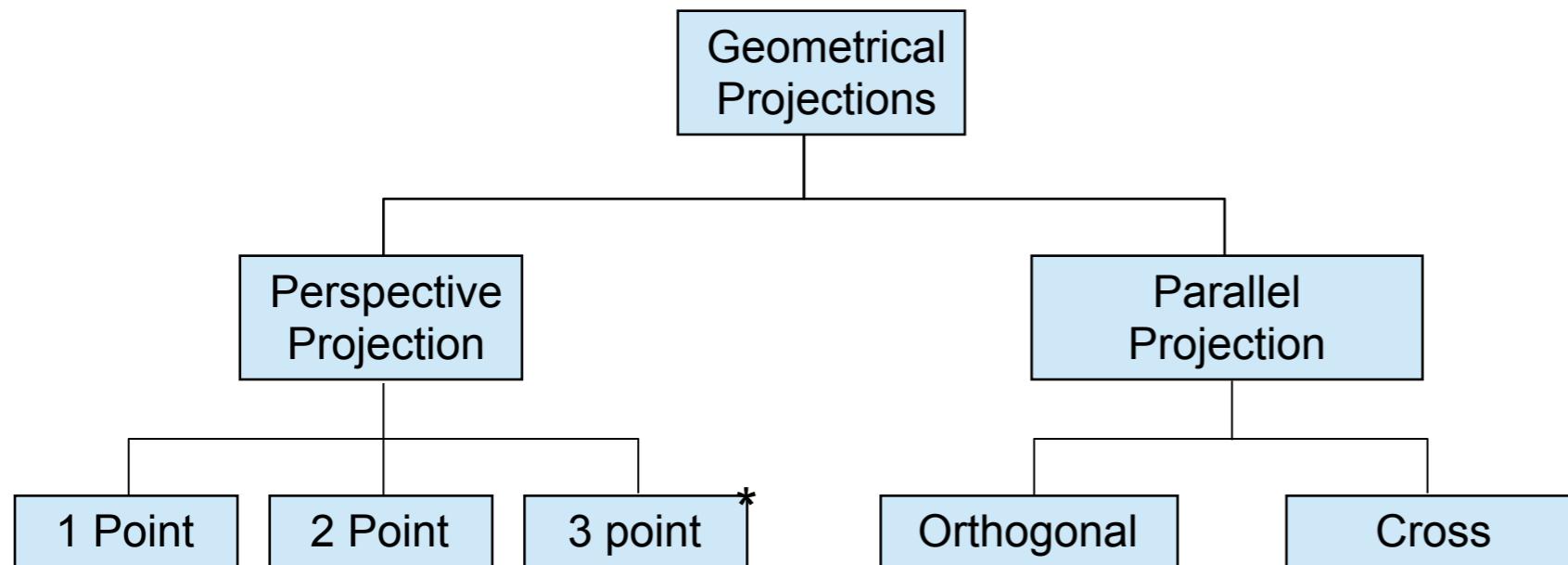
Projection in 2D

Camera Model

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Pinhole camera model



Geometric projections in Computer Graphics

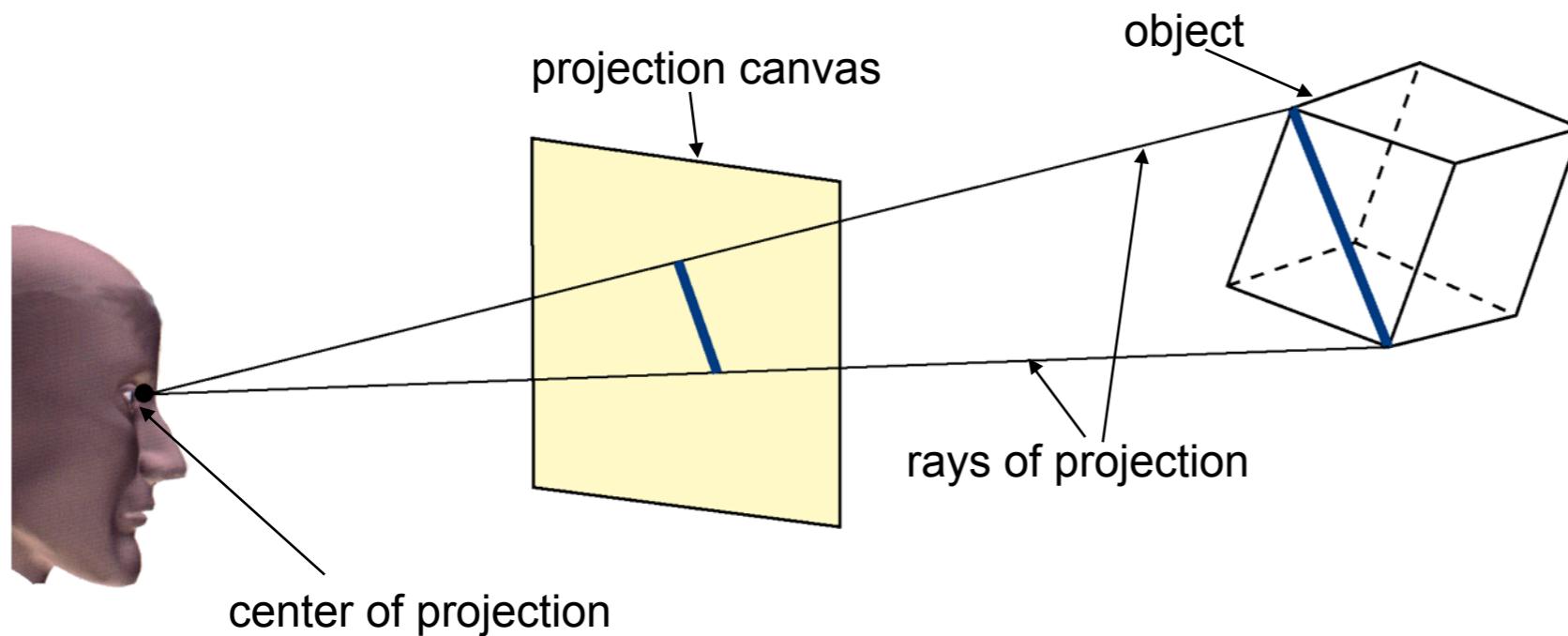
In computer graphics (CG), a projection is considered of a 3-dimensional object onto a 2-dimensional canvas. Therefore, CG uses so called **geometric projections**, which calculate 2D surface coordinates for a 3D object.

Affine Transformation:
A affine projection is a linear 3D transformation (rotation and translation), which preserves the ratio and geometric structure of all lines in the image, but not the length of lines.

* number of vanishing points

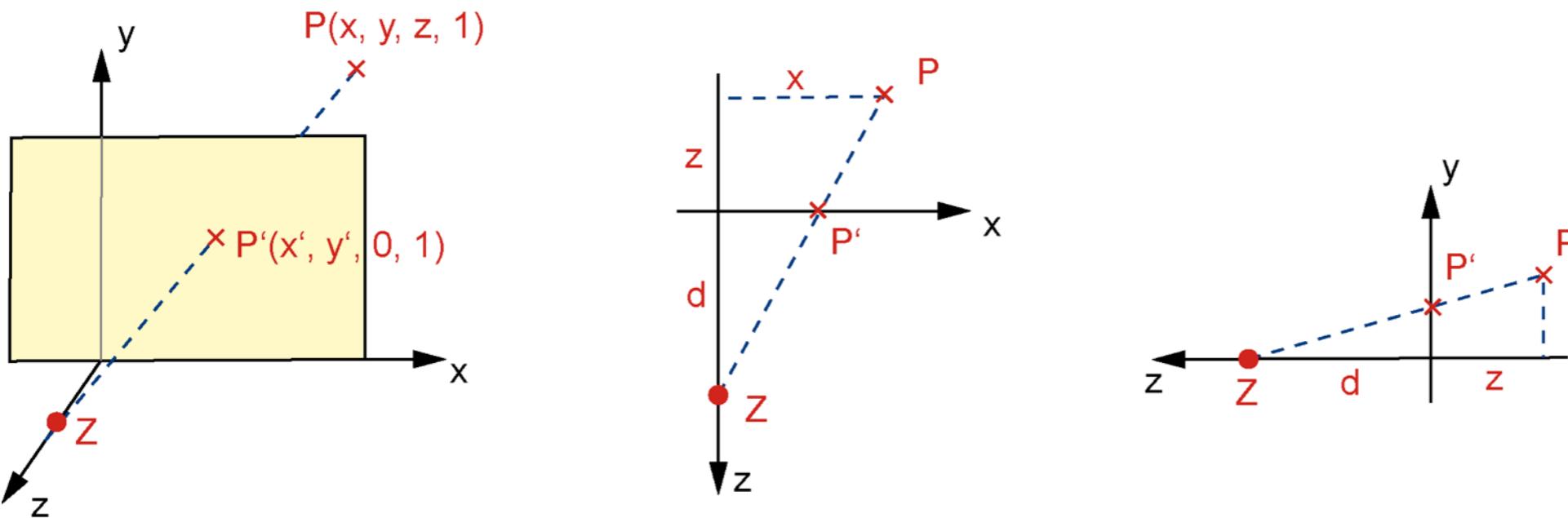
Perspective Projection

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perspective projection

A perspective projection maps all objects realistically to a 2D surface. It correlates with the human viewing. But, it is not an affine projection: dimensions, aspect ratios, and angles are changed during the projection.

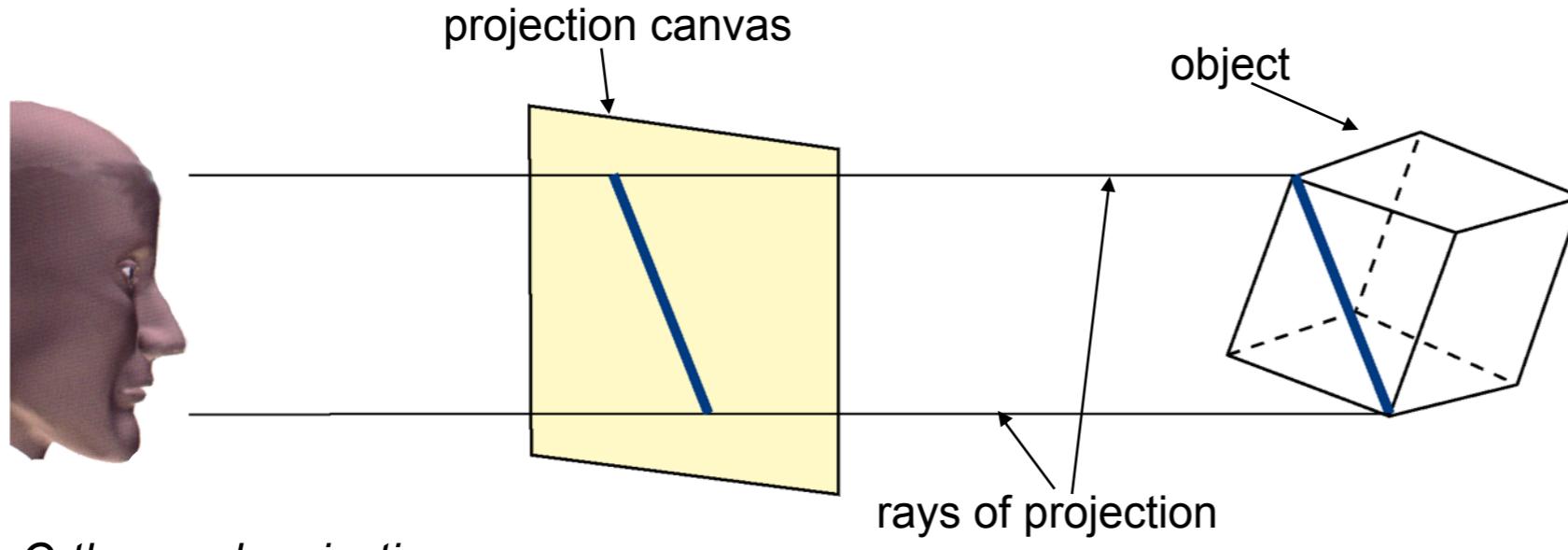


Concept of the perspective projection

$$x' = \frac{d \cdot x}{z + d}$$
$$y' = \frac{d \cdot y}{z + d}$$
$$z' = 0$$

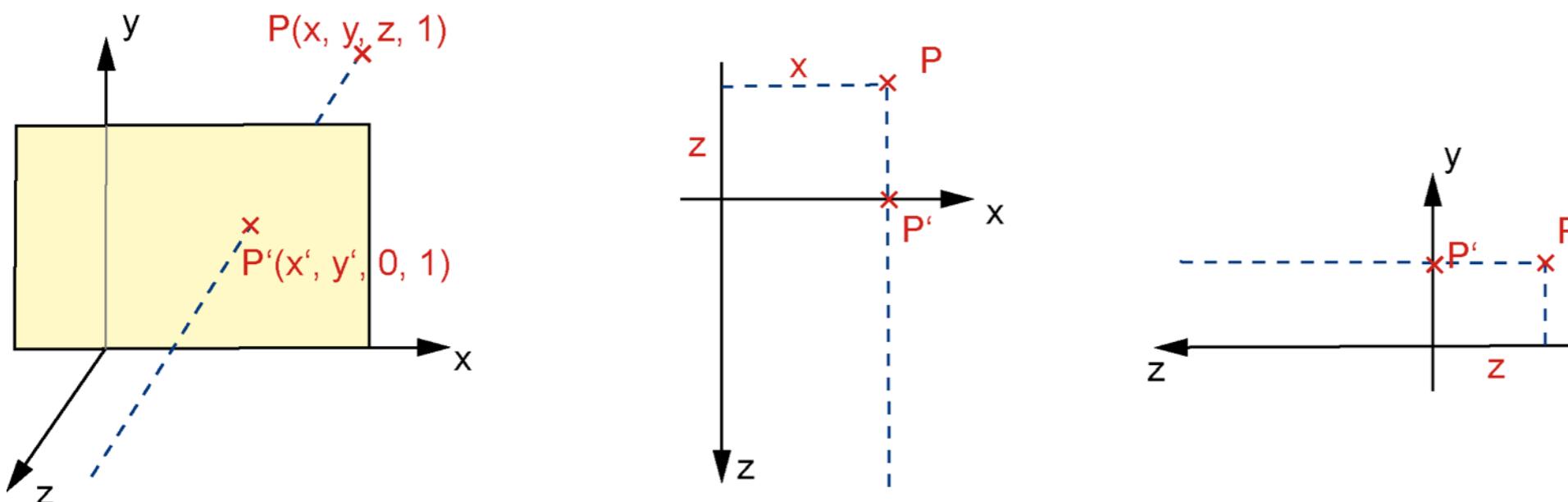
Orthogonal Projection

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Orthogonal projection

From a mathematical point of view, a parallel projection is a theoretical projection where the rays of projections vanish at a vanishing point at infinite distance. Thus, the projection rays are considered as parallel.
The projection is an affine projection: aspect ratios, distances, and angles are kept.

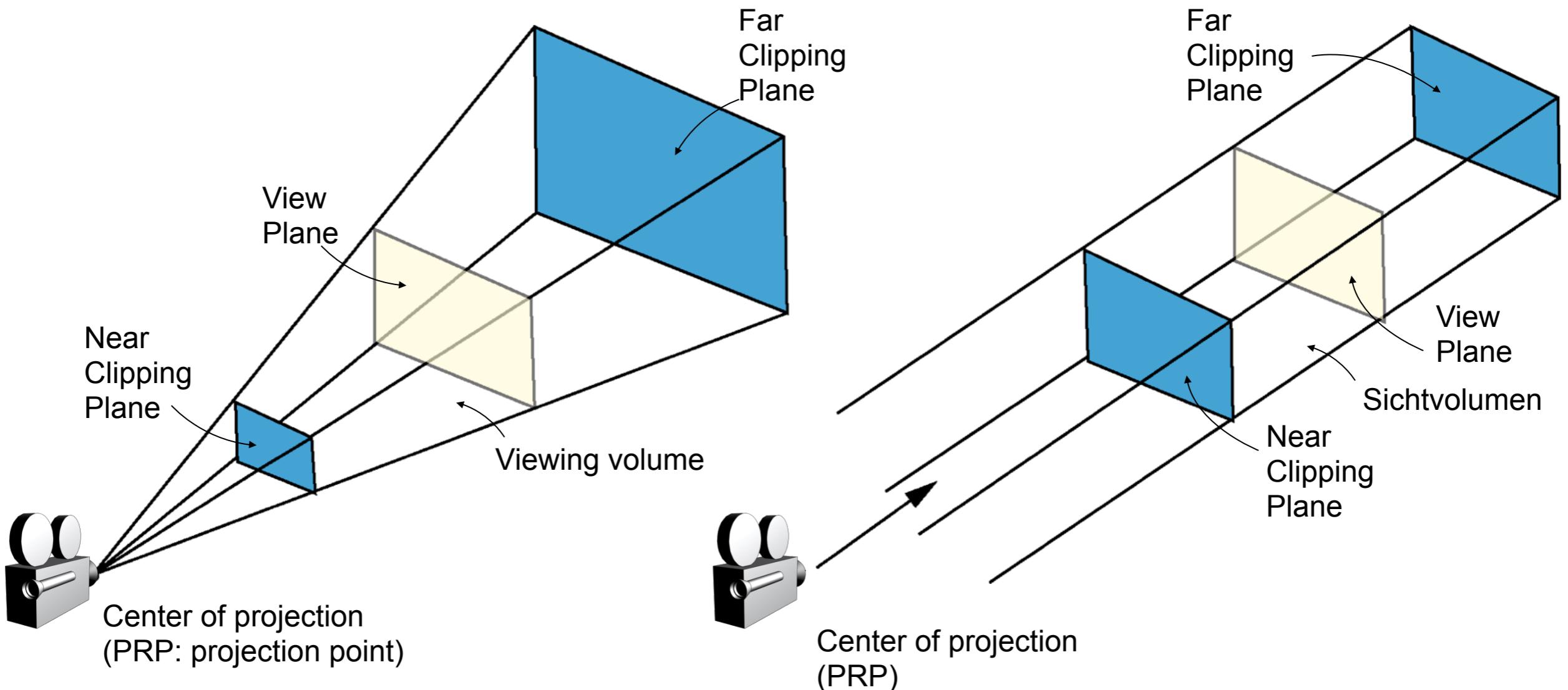


Concept of orthogonal projection

$$\begin{aligned}x' &= x \\y' &= y \\z' &= 0\end{aligned}$$

Viewing Volume

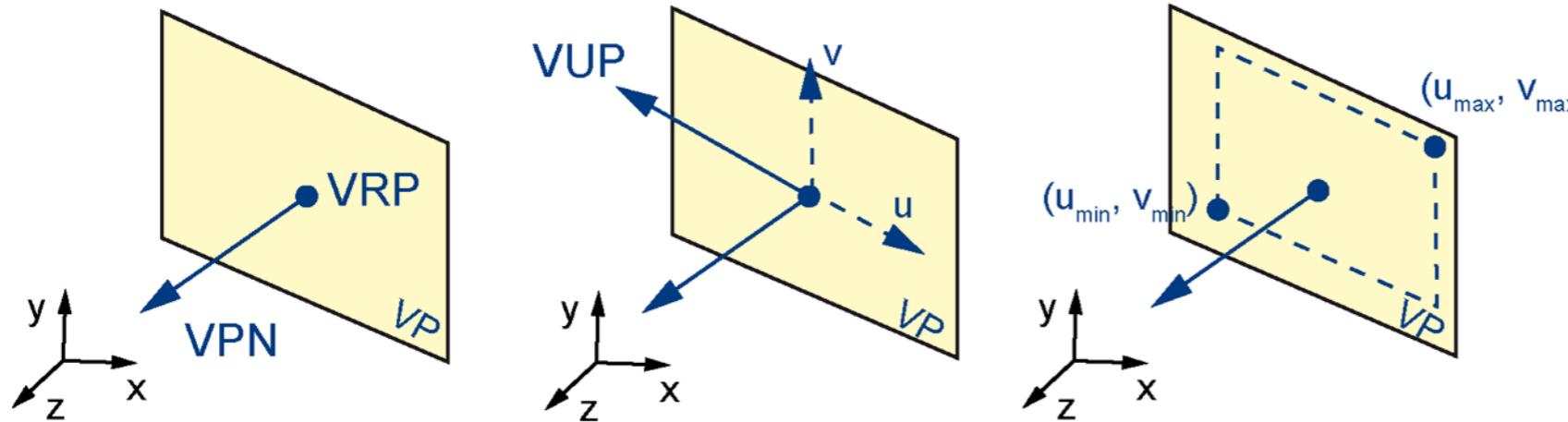
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The viewing volume of a perspective and an orthogonal projection.

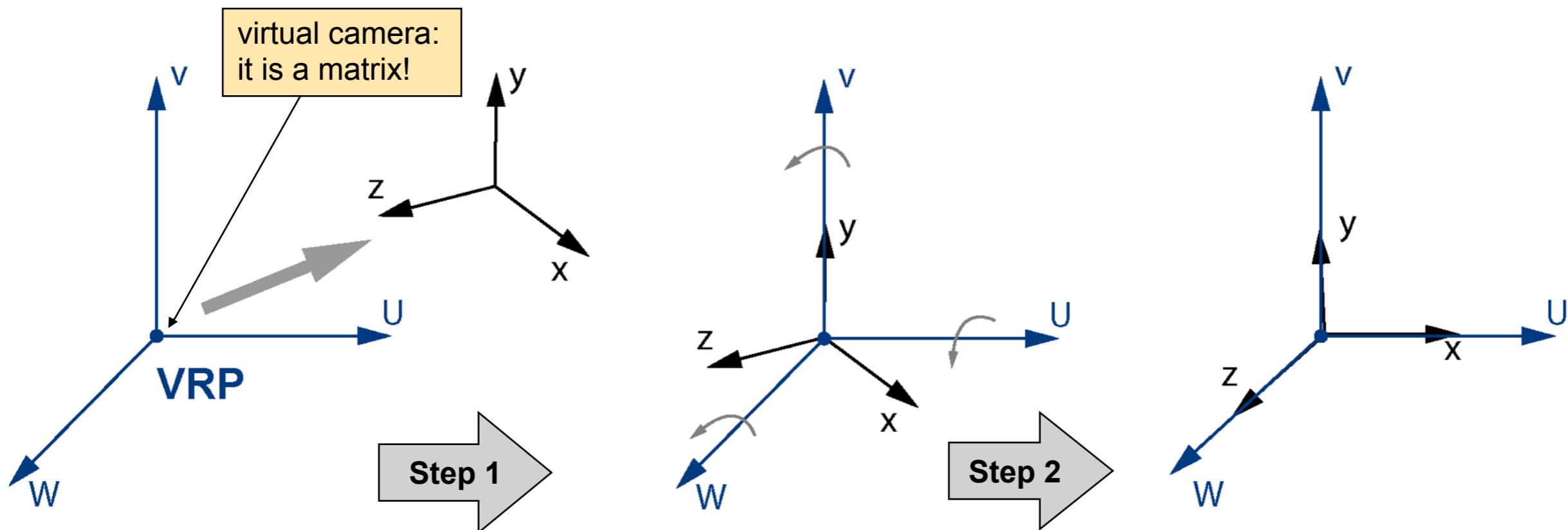
Camera Coordinates & View Transformation

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- VP: View Plane
- VRP: View Reference Point (camera eye point)
- VUP: View Up Vector
- VPN: View Plan Normal Vector (look at vector)

Coordinates of a view reference frame, the virtual camera in the scene.



The view transformation: from 3D model to 2D projection

View Transformations

Step 1: Displacement of the camera VRP into the origin.

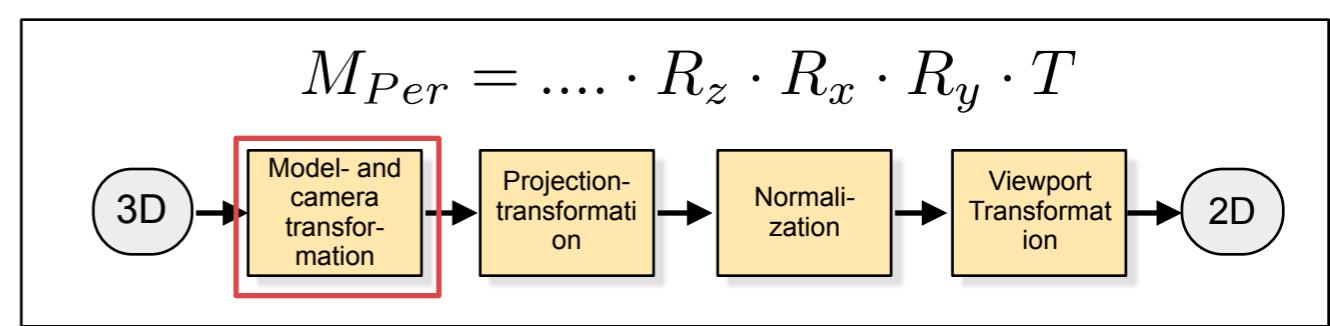
$$T = \begin{bmatrix} 1 & 0 & 0 & -vRP_x \\ 0 & 1 & 0 & -vRP_y \\ 0 & 0 & 1 & -vRP_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 2.1: Rotation around the z- and x-axis. Projection normal vector and viewing direction should meet.

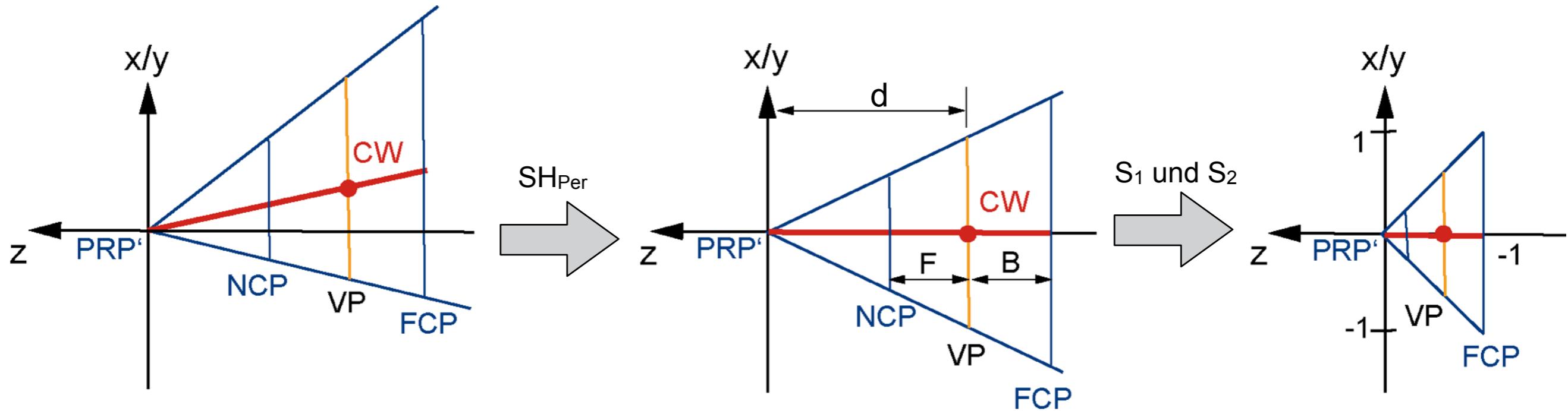
$$R_y = \begin{bmatrix} \frac{vpn_z}{p} & 0 & -\frac{vpn_x}{p} & 0 \\ 0 & 1 & 0 & 0 \\ \frac{vpn_x}{p} & 0 & \frac{vpn_z}{p} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & p & -vpn_y & 0 \\ 0 & vpny & p & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 2.2: Rotation around the y-axis. All axis of the camera should align with the origin.

$$R_z = \begin{bmatrix} \frac{vup'_y}{q} & -\frac{vup'_x}{q} & 0 & 0 \\ -\frac{vup'_x}{q} & \frac{vup'_y}{q} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



View Transformations



Perspective projection: shearing of the view volume

Shearing: this aligns the center line of the view volume, which crosses the center of the view window (CW), with the world coordinate axis of the view direction.

Perspective projection: mapping of the view volume into a canonical view volume

The **canonical view volume** is a unit volume, which contains all the information of the entire visible scene. It is a frustum of a pyramid for a perspective projection.

NCP: near clipping plane

VP: view plane

FC: far clipping plane

PRP: projection reference point

View Transformations

ARLAB

Step 3: shearing of the view volume

$$SH_{Per} = \begin{bmatrix} 1 & 0 & -\frac{vrp'_x + \frac{1}{2}(u_{min}+u_{max})}{vrp'_z} & 0 \\ 0 & 1 & -\frac{vrp'_y + \frac{1}{2}(v_{min}+v_{max})}{vrp'_z} & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix}$$

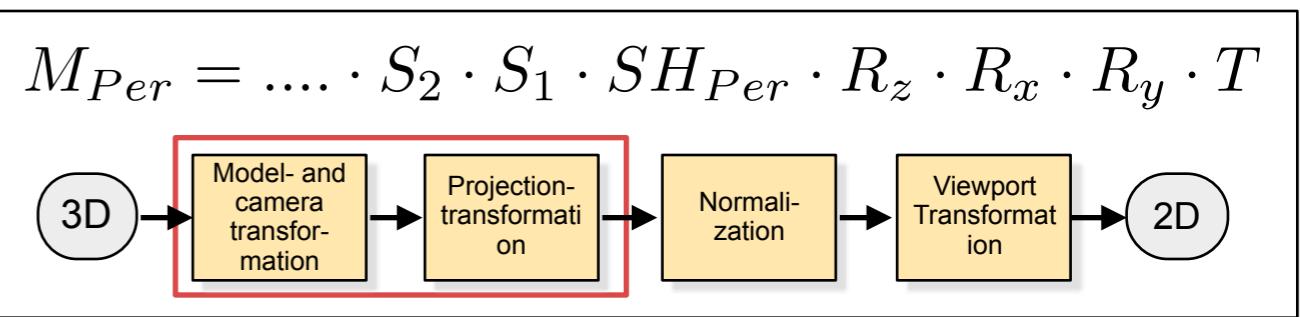
Step 4: projection of the view volume into a canonical view frustum

$$S_1 = \begin{bmatrix} \frac{2 \cdot d}{u_{max}-u_{min}} & 0 & 0 & 0 \\ 0 & \frac{2 \cdot d}{v_{max}-v_{min}} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$S_2 = \begin{bmatrix} \frac{1}{d+B} & 0 & 0 & 0 \\ 0 & \frac{1}{d+B} & 0 & 0 \\ 0 & 0 & \frac{1}{d+B} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

d : distance virtual camera - View Plan

B : distance View Plan - Far Clipping Plane



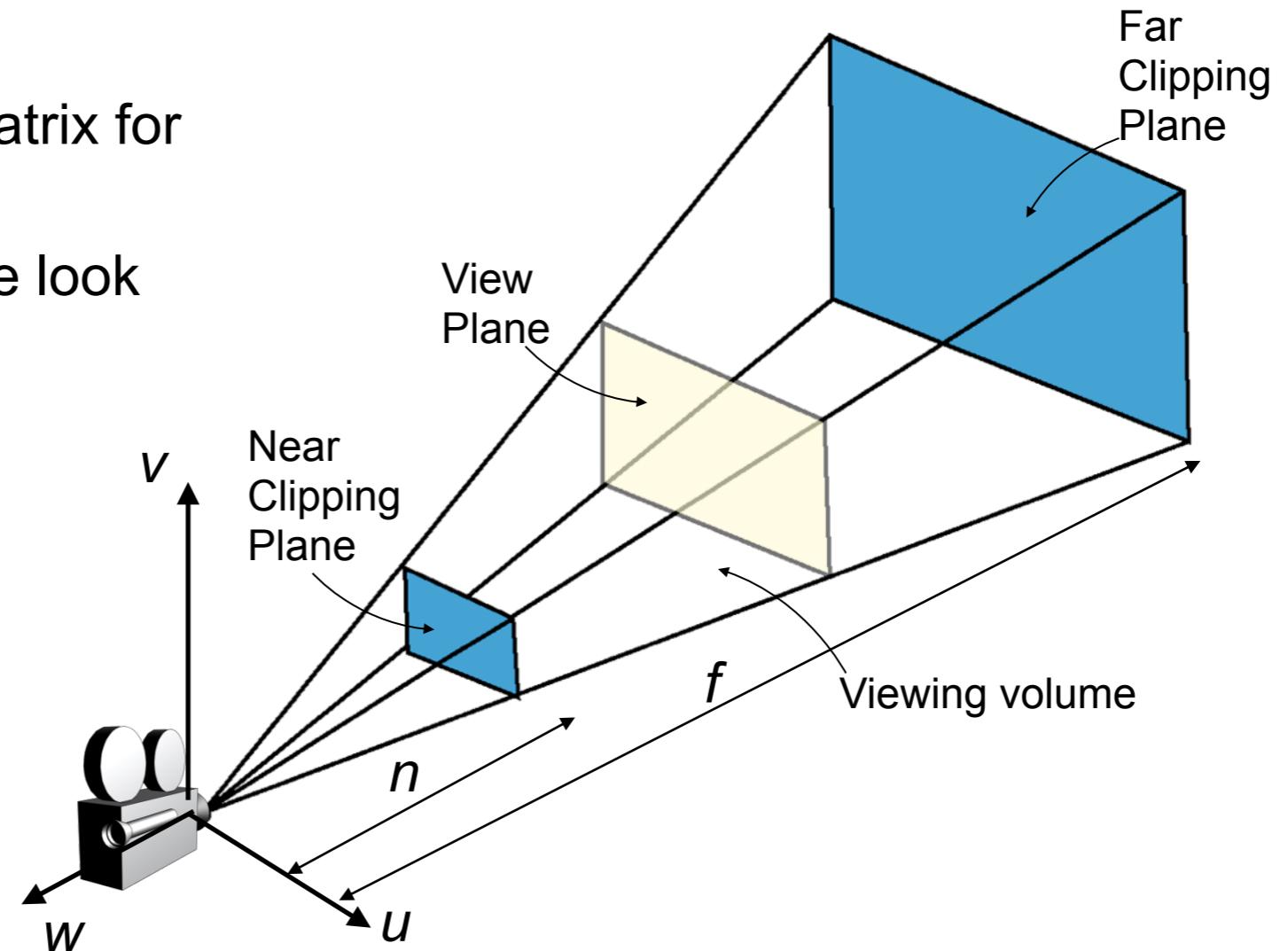
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Projective Transformation Summarized

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Summarized, the projection matrix for perspective projections.

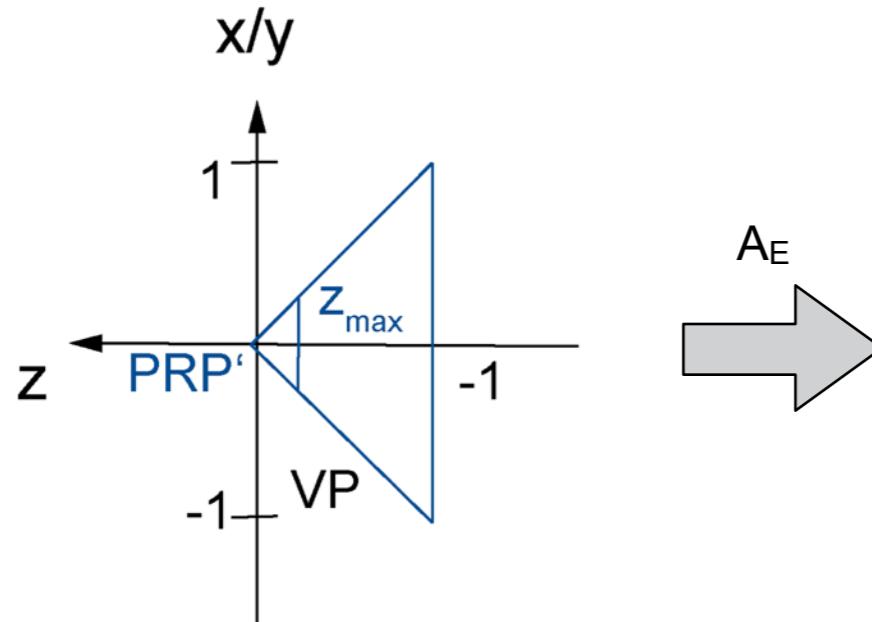
Note, in computer graphics, we look into the negative direction.



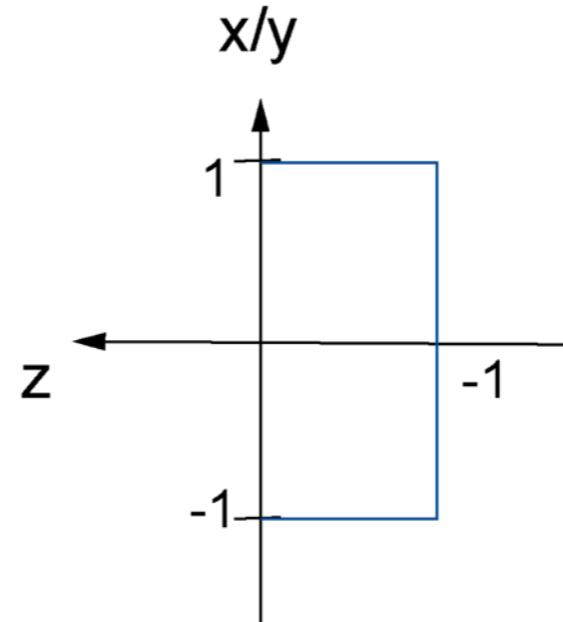
$$\mathbf{M}_{per} = \begin{bmatrix} \frac{1}{f \tan \theta_h / 2} & 0 & 0 & 0 \\ 0 & \frac{1}{f \tan \theta_v / 2} & 0 & 0 \\ 0 & 0 & \frac{1}{f} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_x & u_y & u_z & 0 \\ v_x & v_y & v_z & 0 \\ w_x & w_y & w_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -P_x \\ 0 & 1 & 0 & -P_y \\ 0 & 0 & 1 & -P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Normalization

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Open the frustum to a cuboid

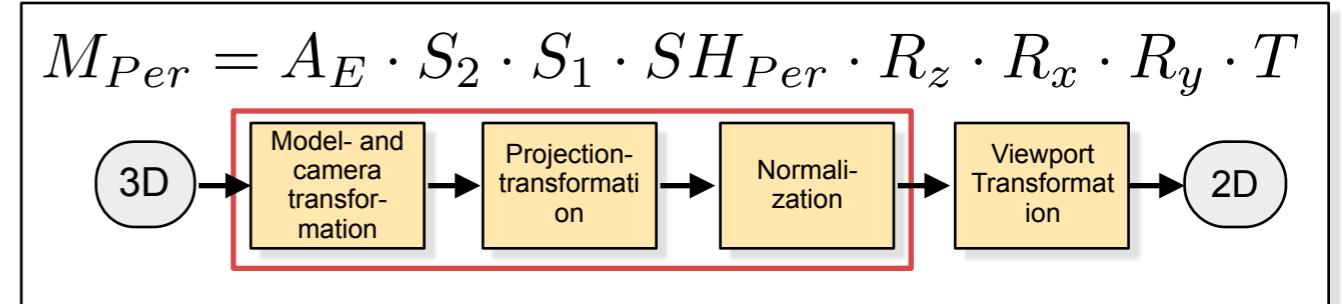


The normalization step transfers all data inside the frustum of a pyramid into a unit cuboid with edge dimensions
 $-1 \leq x \leq 1$, $-1 \leq y \leq 1$, and $0 \leq z \leq -1$.

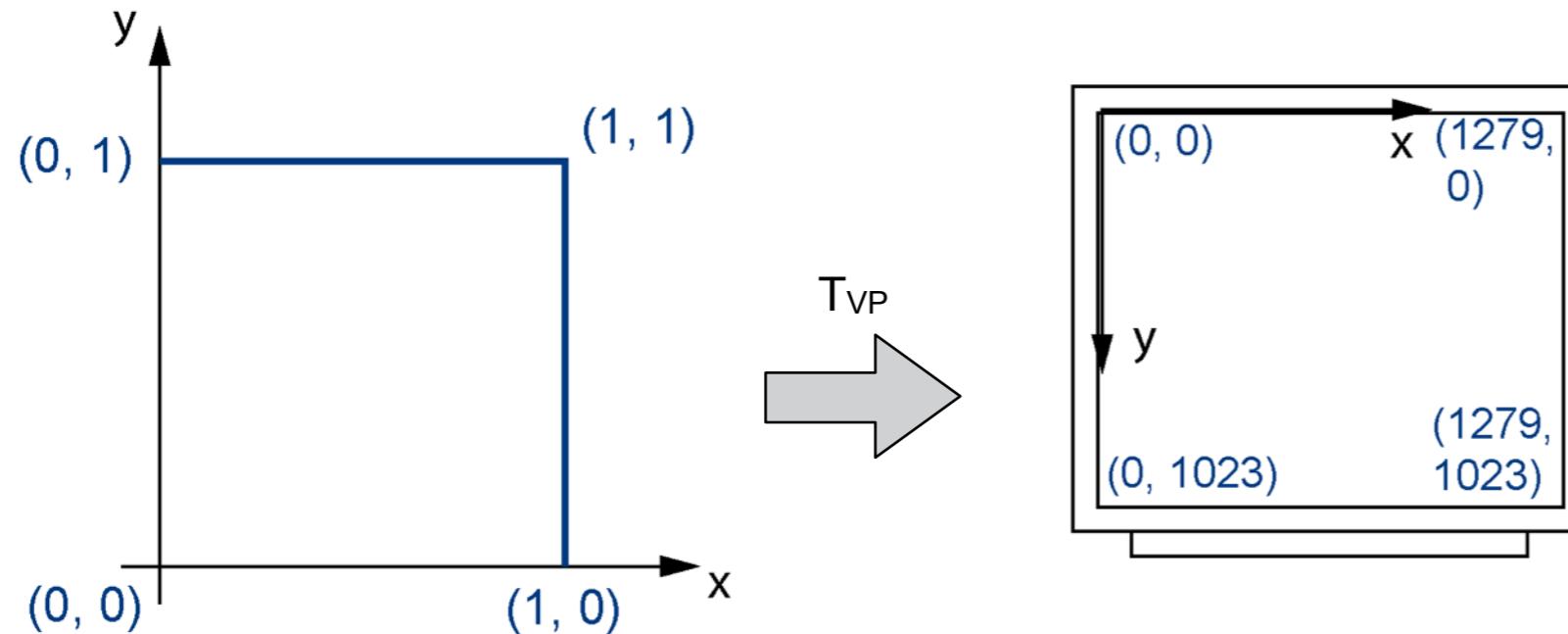
Step 5: open the frustum of a pyramid to a cuboid

$$A = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & \frac{-1}{1+t_{max}} & \frac{z_{max}}{1+t_{max}} \\ 0 & 0 & 1 & 0 \end{bmatrix}, \text{ with } z_{max} = \frac{d-F}{d+B} \text{ und } z_{max} \neq -1$$

$$A_E = \begin{bmatrix} -\frac{1}{1} & 0 & \frac{1}{1} & 0 \\ 0 & -\frac{1}{2} & \frac{1}{1} & 0 \\ 0 & 0 & \frac{-1}{1+t_{max}} & \frac{z_{max}}{1+t_{max}} \\ 0 & 0 & 1 & 0 \end{bmatrix}$$



Viewport-Transformation

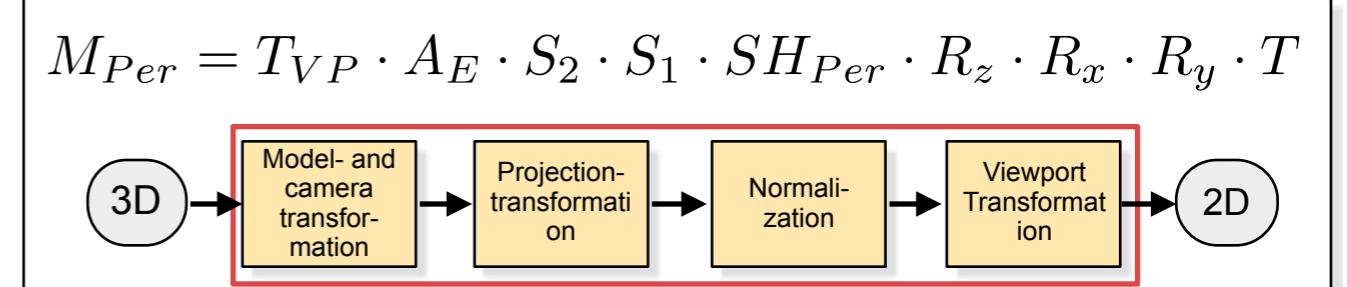


The viewport transformation maps the visual data in the unit cuboid to the pixel ranges in x and y of the screen.

Transformation of unit coordinates into screen coordinates. The example screen has a resolution of 1280 x 1024 pixels

Step 6: presentation of a 3-dimensional unit cuboid on a 2D screen

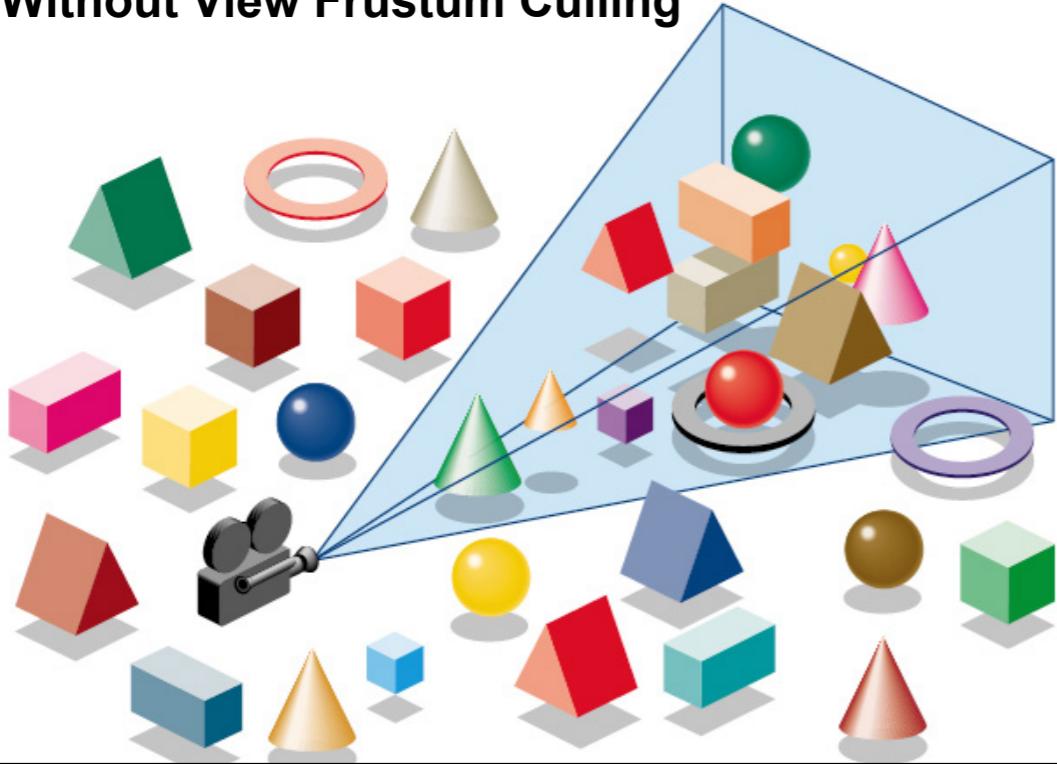
$$T_{VP} = \begin{bmatrix} x_{max} & 0 & 0 & 0 \\ 0 & -y_{max} & 0 & y_{max} \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix}$$



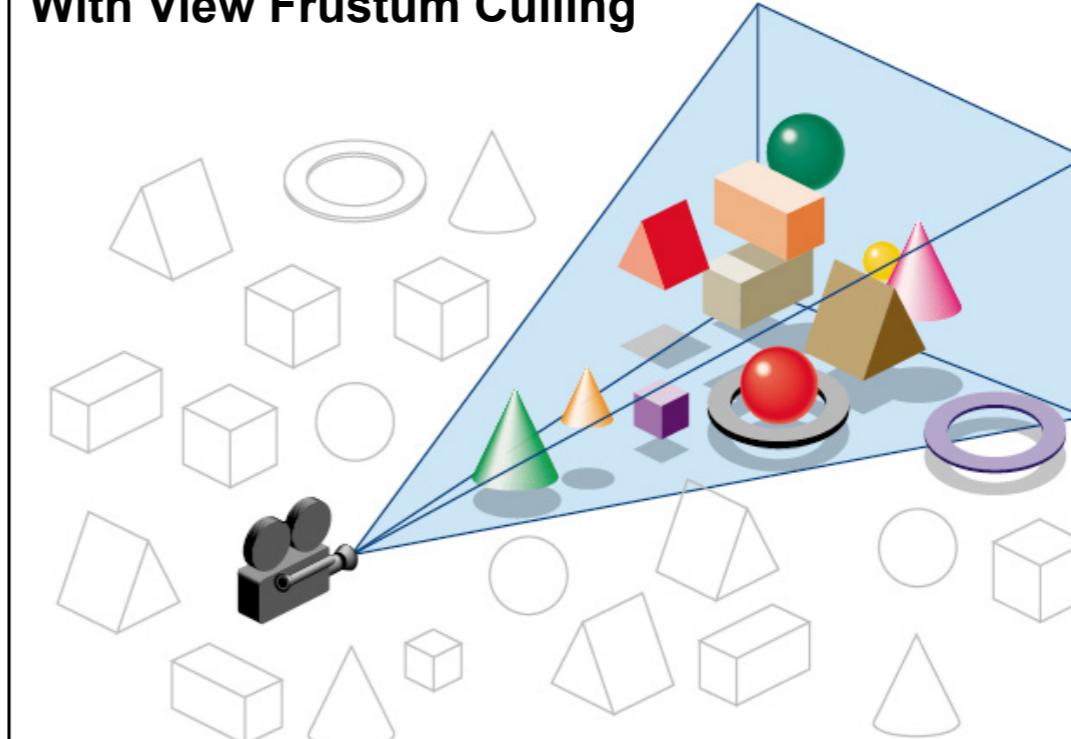
Culling Operations

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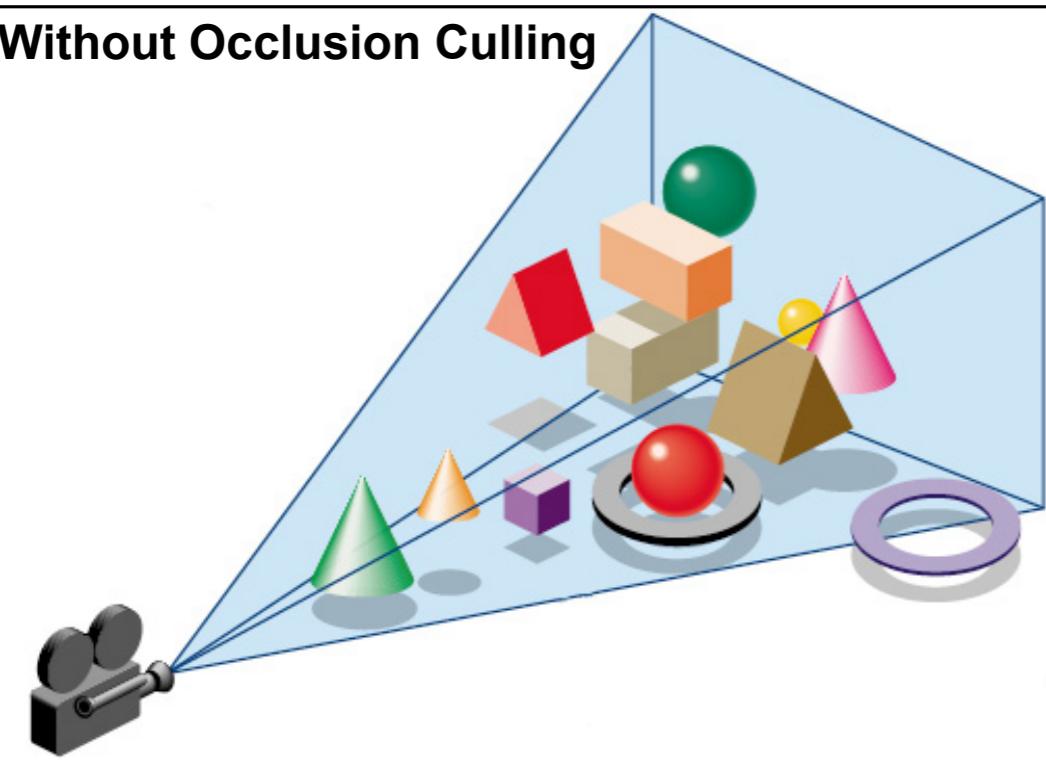
Without View Frustum Culling



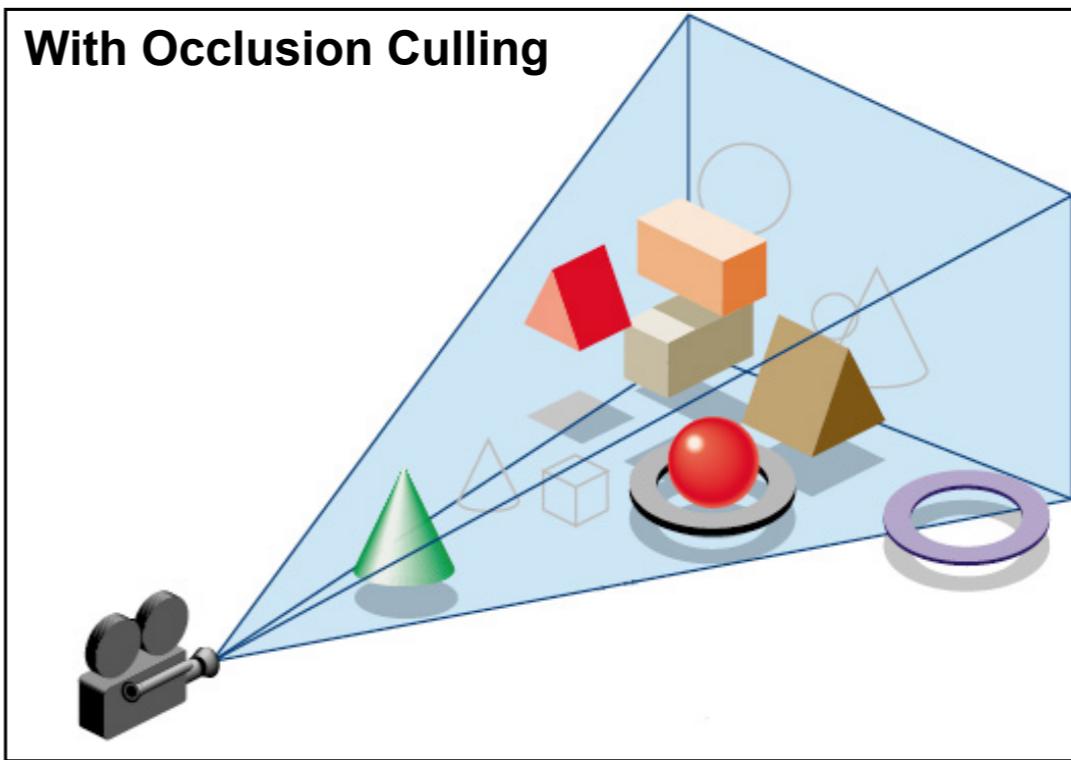
With View Frustum Culling



Without Occlusion Culling



With Occlusion Culling

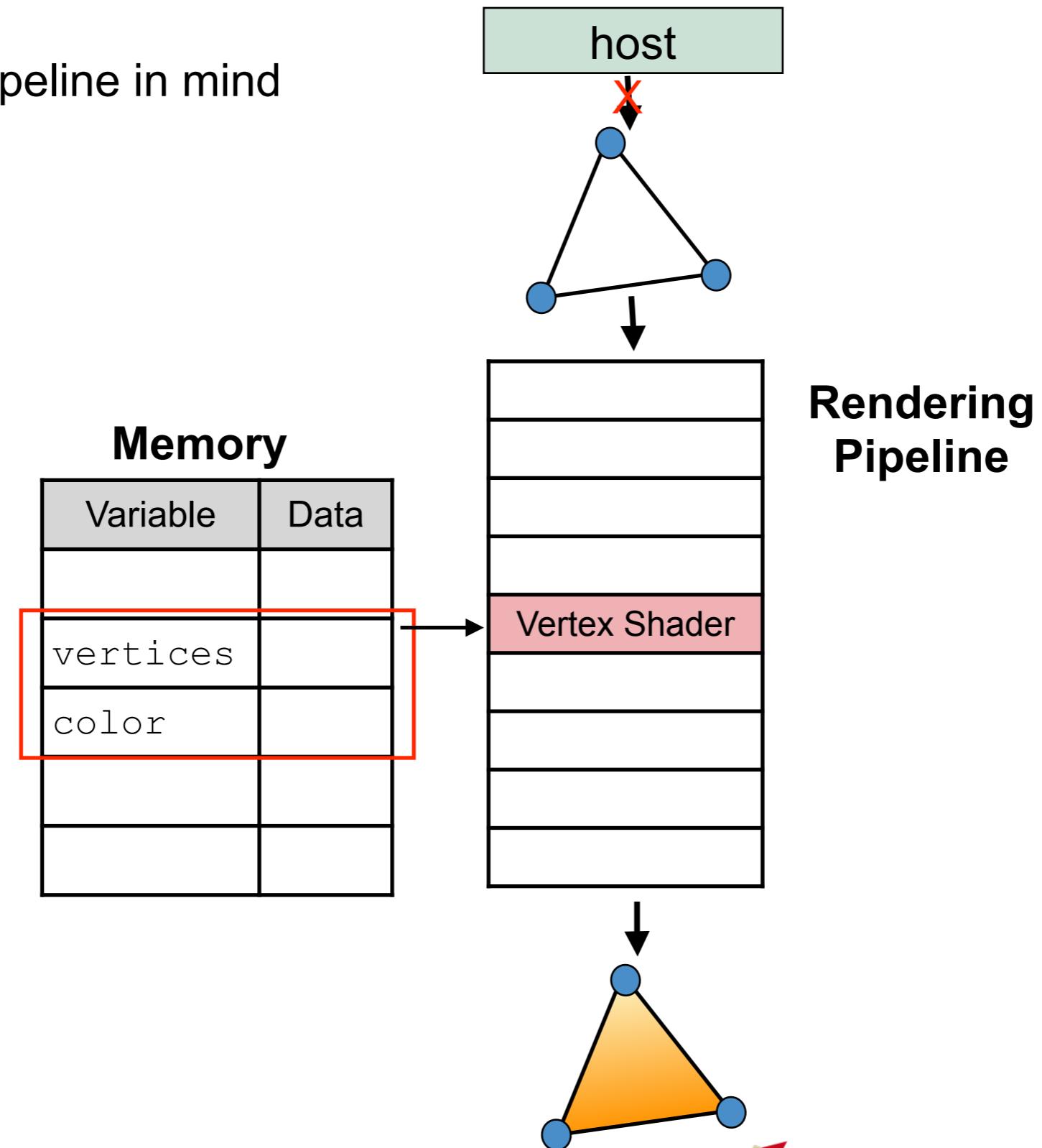


Viewing and Transformation in OpenGL

Pipeline model

ARLAB

Keep the rendering pipeline in mind



Example Shader Code

ARLAB

Shader source code that you can find in our example programs

```
static const string vs_string =
    "#version 410 core
"
"uniform mat4 projectionMatrix;
"uniform mat4 viewMatrix;
"uniform mat4 modelMatrix;
"in vec3 in_Position;
"
"in vec3 in_Color;
"out vec3 pass_Color;
"
"void main(void)
"{
"    gl_Position = projectionMatrix * viewMatrix * modelMatrix * vec4(in_Position, 1.0);  \n"
"    pass_Color = in_Color;
"}\n";
```

Example Shader Code

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The matrices are defined as uniform variables

- uniform: qualifier to declare the variable as a shared variable, shared between host computer and graphics card.
 - mat4: a GLSL 4x4 matrix

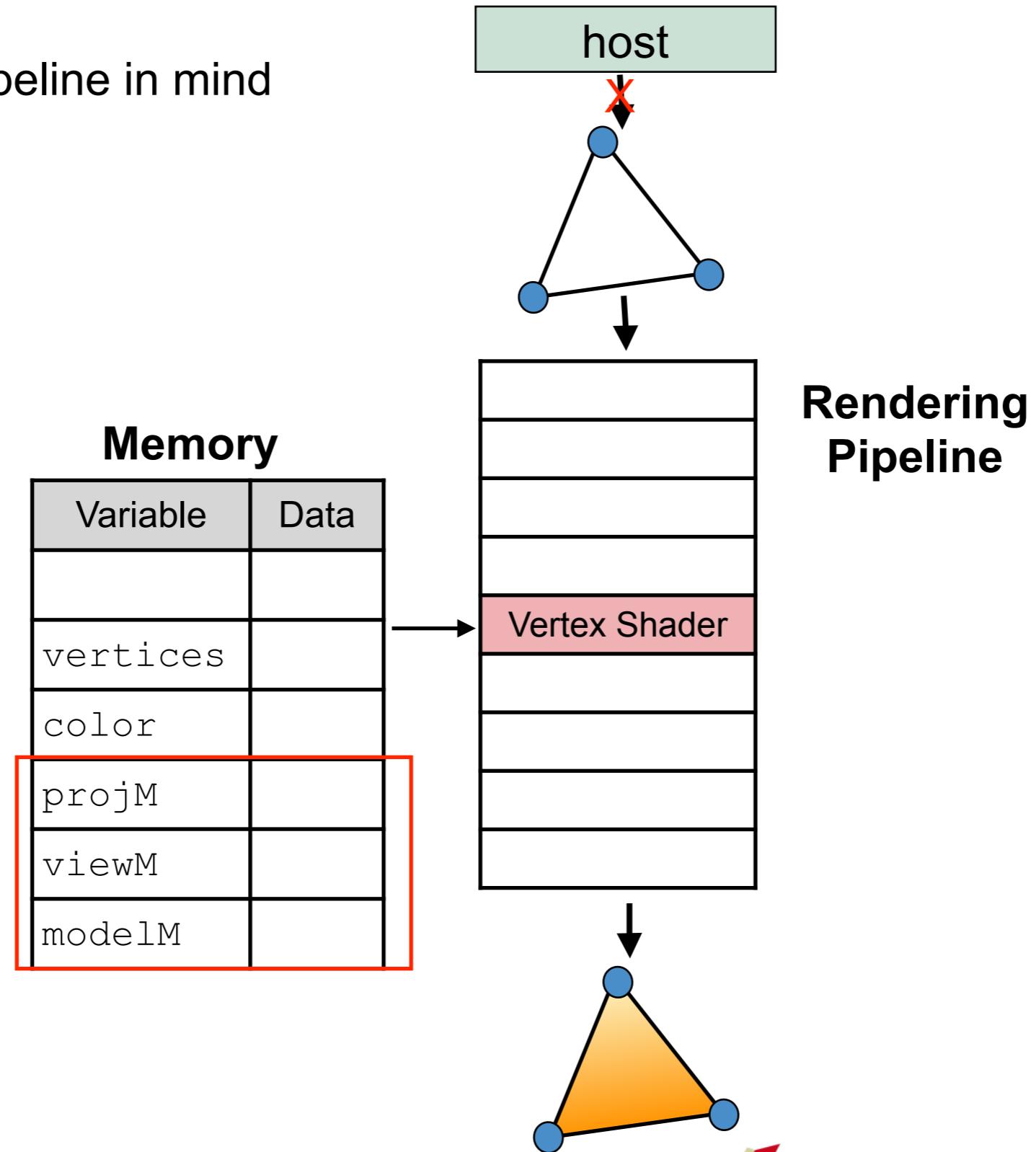
$$\mathbf{M} = \begin{bmatrix} r_{01} & r_{02} & r_{03} & t_x \\ r_{11} & r_{12} & r_{13} & t_y \\ r_{21} & r_{22} & r_{23} & t_z \\ r_{31} & r_{32} & r_{33} & 1 \end{bmatrix}$$

- **Model matrix:** the matrix that we use to transform the 3D model from local coordinates to global coordinates
- **View matrix:** the matrix we use to transform the camera
- **ModelView matrix:** the product of both, since in computer graphics, it does not matter whether one move the camera or the model.
- **Projection matrix:** the projection from 3D to a 2D point.

Pipeline model

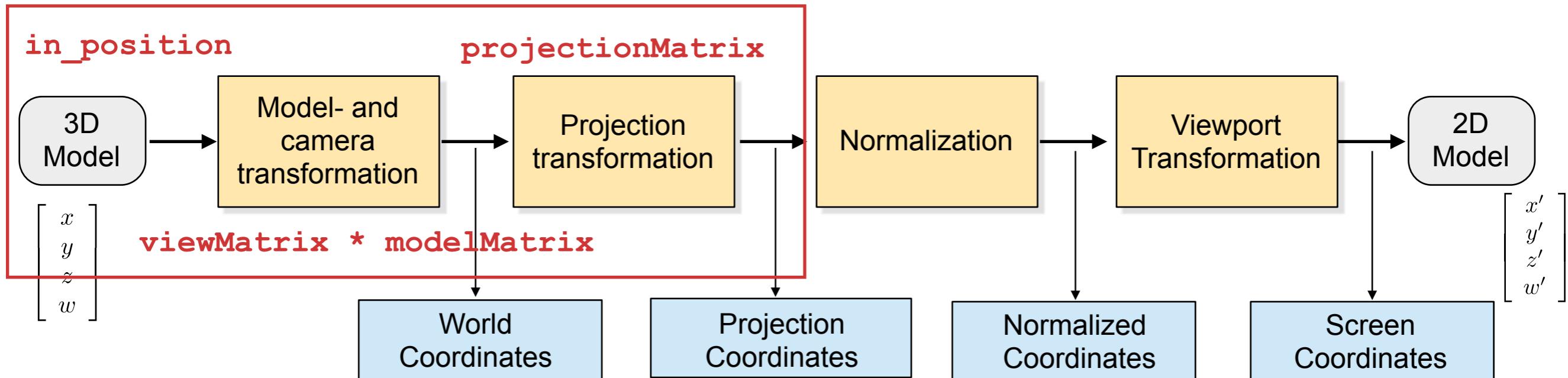
ARLAB

Keep the rendering pipeline in mind

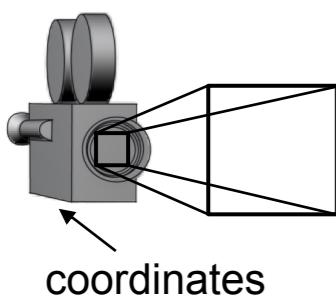


Viewing in 3D

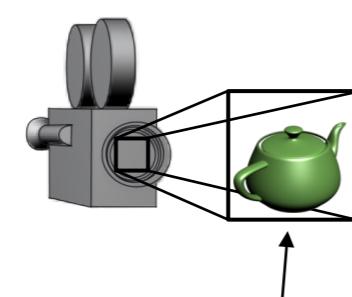
ARLAB



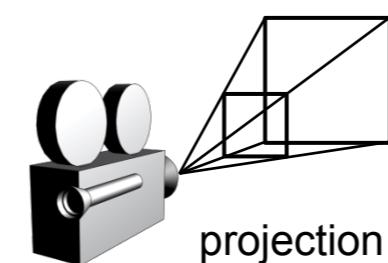
Computer



coordinates



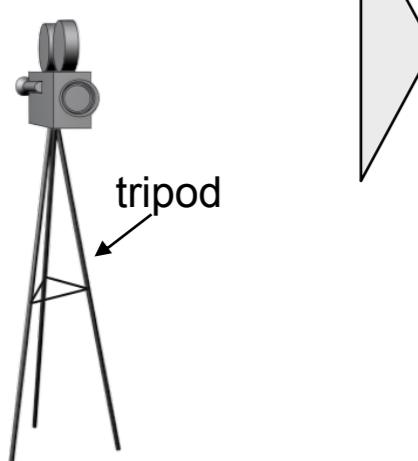
model



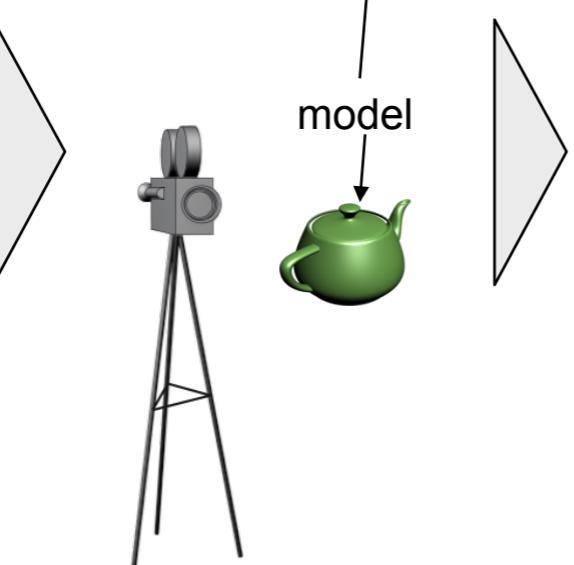
projection



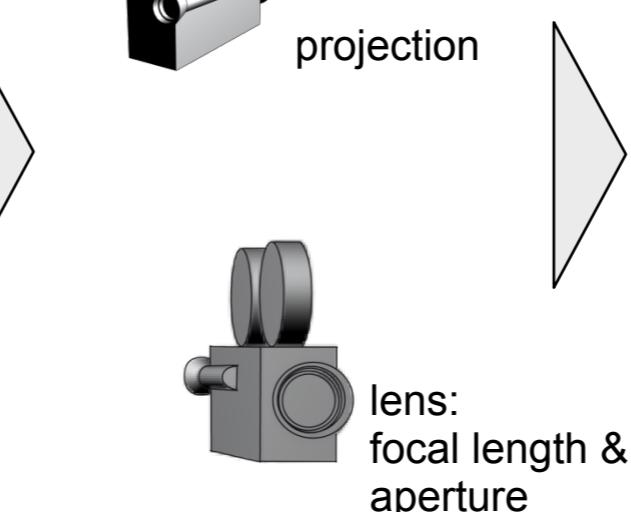
viewport



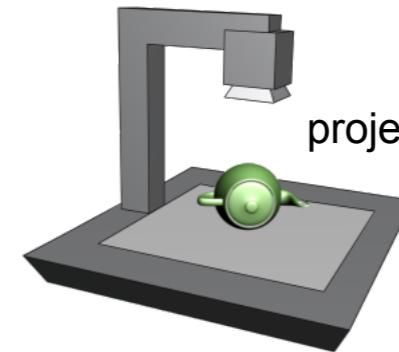
Place the viewing volume
in 3D space



Place a model in front
of the camera



lens:
focal length &
aperture



project picture to sensor

Set the geometrical shape of
the view volume

Projection in 2D

Example Shader Code

ARLAB

```
static const string vs_string =
"#version 410 core
"
"uniform mat4 projectionMatrix;
"uniform mat4 viewMatrix;
"uniform mat4 modelMatrix;
"in vec3 in_Position;
"
"in vec3 in_Color;
"out vec3 pass_Color;
"
"void main(void)
"{
"    gl_Position = projectionMatrix * viewMatrix * modelMatrix * vec4(in_Position, 1.0); \n"
"    pass_Color = in_Color; \n"
"} \n";
```

This is the modelview
projection calculation

- `gl_Position`: the built-in *varying* variable to pass the position information to the next step.
Note, `gl_Position` is a vector with 4 elements [x, y, z, 1]

GLM Transformation Matrix



We use the glm transformation matrix

glm::mat4

to represent a 4x4 matrix.

$$\mathbf{M} = \begin{bmatrix} r_{01} & r_{02} & r_{03} & t_x \\ r_{11} & r_{12} & r_{13} & t_y \\ r_{21} & r_{22} & r_{23} & t_z \\ r_{31} & r_{32} & r_{33} & 1 \end{bmatrix}$$

Glm include files:

```
#include <glm/glm.hpp>
#include <glm/gtc/matrix_transform.hpp>
```

in our example code:

```
glm::mat4 projectionMatrix; // Store the projection matrix
glm::mat4 viewMatrix; // Store the view matrix
glm::mat4 modelMatrix; // Store the model matrix
```

GLM Vector 3

We use the glm transformation matrix

glm::vec3

to represent a vector of size 3, and

glm::vec4

to represent a vector of size 4
(homogenous space)

$$\mathbf{p} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

$$\mathbf{p} = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Example:

```
glm::vec3 p = glm::vec3(0.0f, 1.0f, 0.0f);
```

Transformations

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Translation

```
detail::tmat4x4< T > translate (T x, T y, T z)
```

Parameters:

- x, y, z: Specify the x, y, and z coordinates of a translation vector.

Rotation

```
detail::tmat4x4< T > rotate (T angle, T x, T y, T z)
```

Parameters:

- angle: Specifies the angle of rotation, in degrees.
- x, y, z: Specify the x, y, and z coordinates of a vector, respectively.

Scaling

```
detail::tmat4x4< T > scale (T x, T y, T z)
```

Parameters:

- x, y, z: Specify scale factors along the x, y, and z axes, respectively.

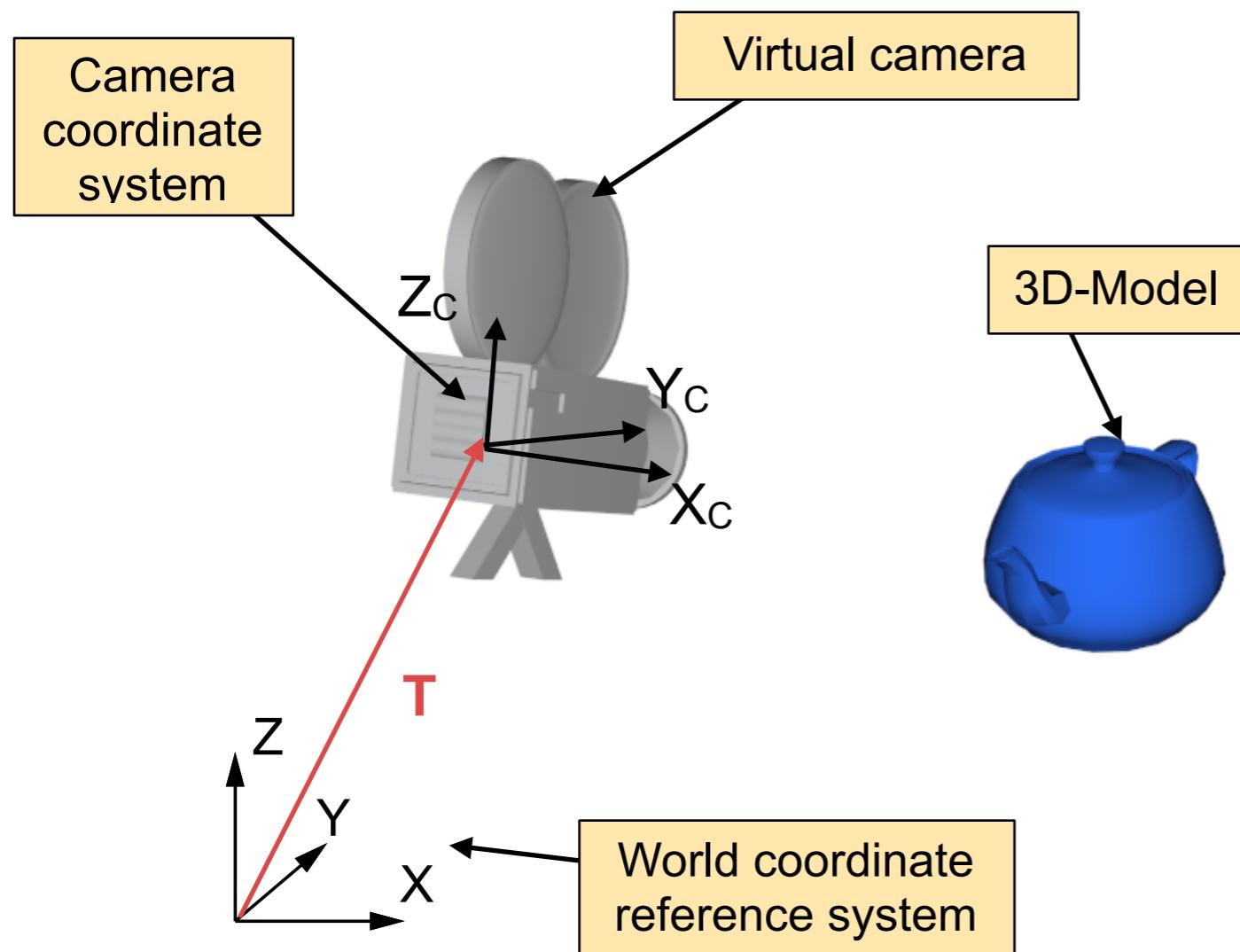
Datatype:

```
detail::tmat4x4< T > this is a glm::mat4
```

Viewing in OpenGL

To Do:

1. Set a projection with `glm::perspective`
2. Locate and align the virtual camera with `glm::lookAt`



Set a Projection

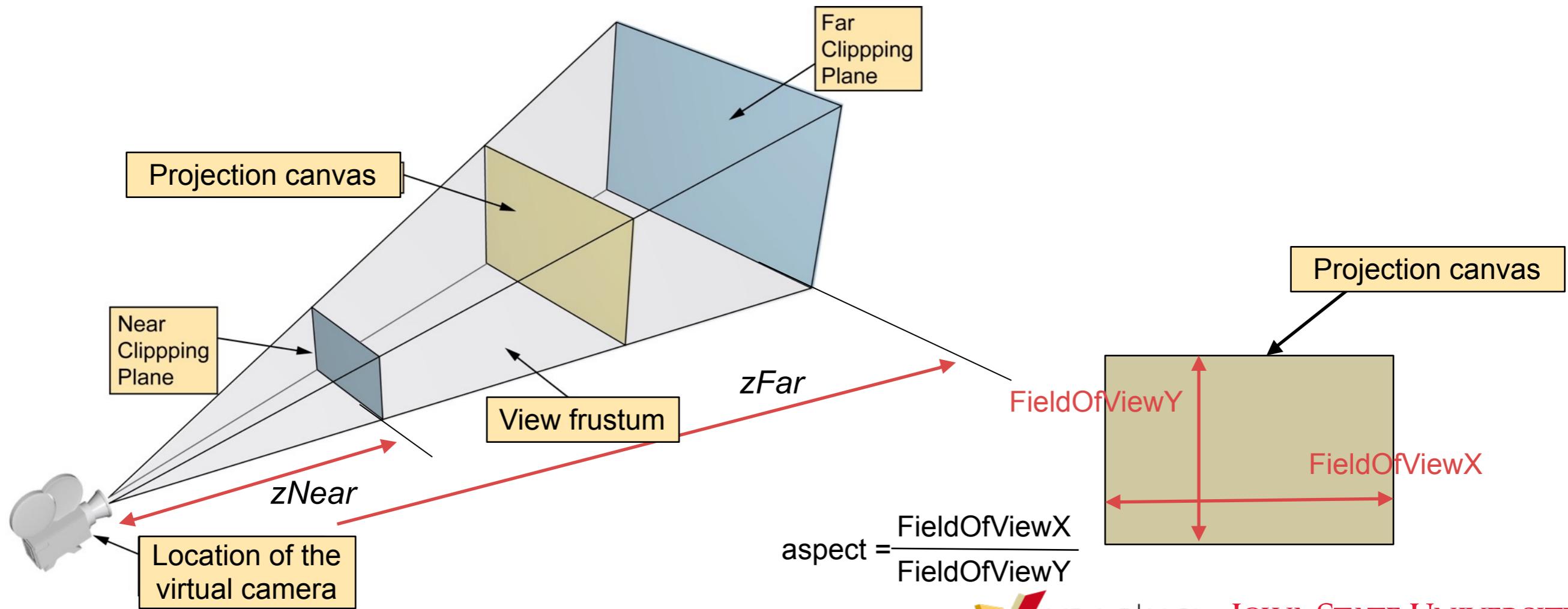
Set a Projection

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```
glm::mat4 perspective (T const &fovy, T const &aspect, T const &near, T const &far)
```

Parameters:

- fovy: Specifies the field of view angle, in degrees, in the y direction.
- aspect: Specifies the aspect ratio that determines the field of view in the x direction. The aspect ratio is the ratio of x (width) to y (height).
- zNear: Specifies the distance from the viewer to the near clipping plane (always positive).
- zFar: Specifies the distance from the viewer to the far clipping plane (always positive).



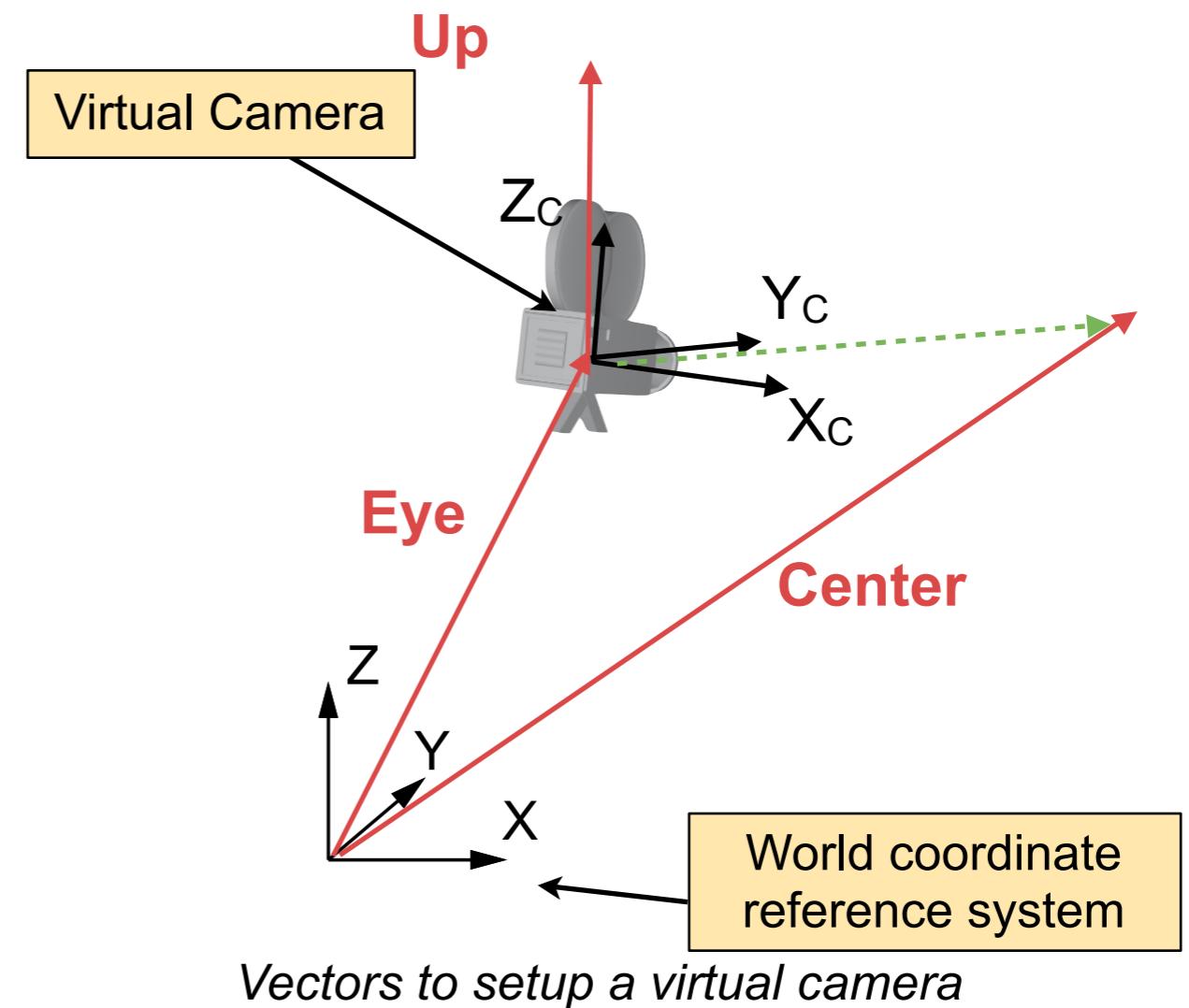
Camera Location and Orientation

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```
glm::mat4 lookAt (  
detail::tvec3< T > const &eye,  
detail::tvec3< T > const &center,  
detail::tvec3< T > const &up)
```

Parameters:

- eye: Specifies the position of the eye.
- center
Specifies the position of the point to look to.
- up: Specifies the direction of the up vector.



Example

ARLAB

Global defined coordinates

```
glm::mat4 projectionMatrix; // Store the projection matrix  
glm::mat4 viewMatrix; // Store the view matrix  
glm::mat4 modelMatrix; // Store the model matrix
```

Init part of the program

Example and Structure

Global

```
glm::mat4 projectionMatrix; // Store the projection matrix
glm::mat4 viewMatrix; // Store the view matrix
glm::mat4 modelMatrix; // Store the model matrix

int main(int argc, const char * argv[])
{
```

Program init

```
projectionMatrix = glm::perspective(1.57f, (float)800 / (float)600, 0.1f,
100.f);

modelMatrix = glm::translate(0.0f, 0.0f, 0.0f);

viewMatrix = glm::lookAt( glm::vec3(0.0f, 0.0f, 1.5f),
glm::vec3(0.0f, 0.0f, 0.0f),
glm::vec3(0.0f, 1.0f, 0.0f));
```

main loop

```
}
```

Global variables can be accessed at any location in your program.
(qualifier **extern** is required in different files)

Question

ARLAB

What do I have to do if I have two or more models and all models should be placed at a different location?

Solutions

- Multiple model variables
- Change the content before you change the content.

Example and Structure

```
int main(int argc, const char * argv[])
```

```
{
```

Program init

```
while
```

Clear the window

```
// Enable the shader program
```

```
glUseProgram(program);
```

```
glBindVertexArray(vaoID[0]);  
modelMatrix = glm::translate(0.0f  
[ something more ]  
glDrawArrays(GL_TRIANGLE_STRIP, 0, 16);
```

```
glBindVertexArray(vaoID[1]);  
modelMatrix = glm::translate(5, 9f  
[ something more ]  
glDrawArrays(GL_TRIANGLE, 0, 16);
```

```
glUseProgram(0);
```

Swap buffers

We change the values before we render the object.
To save memory, keep one variable if you can live with one.

[something more] :
copy the data to your GPU

Uniform Variables

```
GLint glGetUniformLocation( GLuint program, const GLchar *name);
```

Returns the location of a uniform variable

Parameters:

- program: Specifies the program object to be queried.
- name: string containing the name of the uniform variable

Example:

```
int projectionMatrixLocation = glGetUniformLocation(program, "projectionMatrix");
int viewMatrixLocation = glGetUniformLocation(program, "viewMatrix");
int modelMatrixLocation = glGetUniformLocation(program, "modelMatrix");
```

```
static const string vs_string =
"#version 410 core
"
"uniform mat4 projectionMatrix;
uniform mat4 viewMatrix;
uniform mat4 modelMatrix;
in vec3 in_Position;
"
"in vec3 in_Color;
out vec3 pass_Color;
"
```

The names must
be equal

\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n

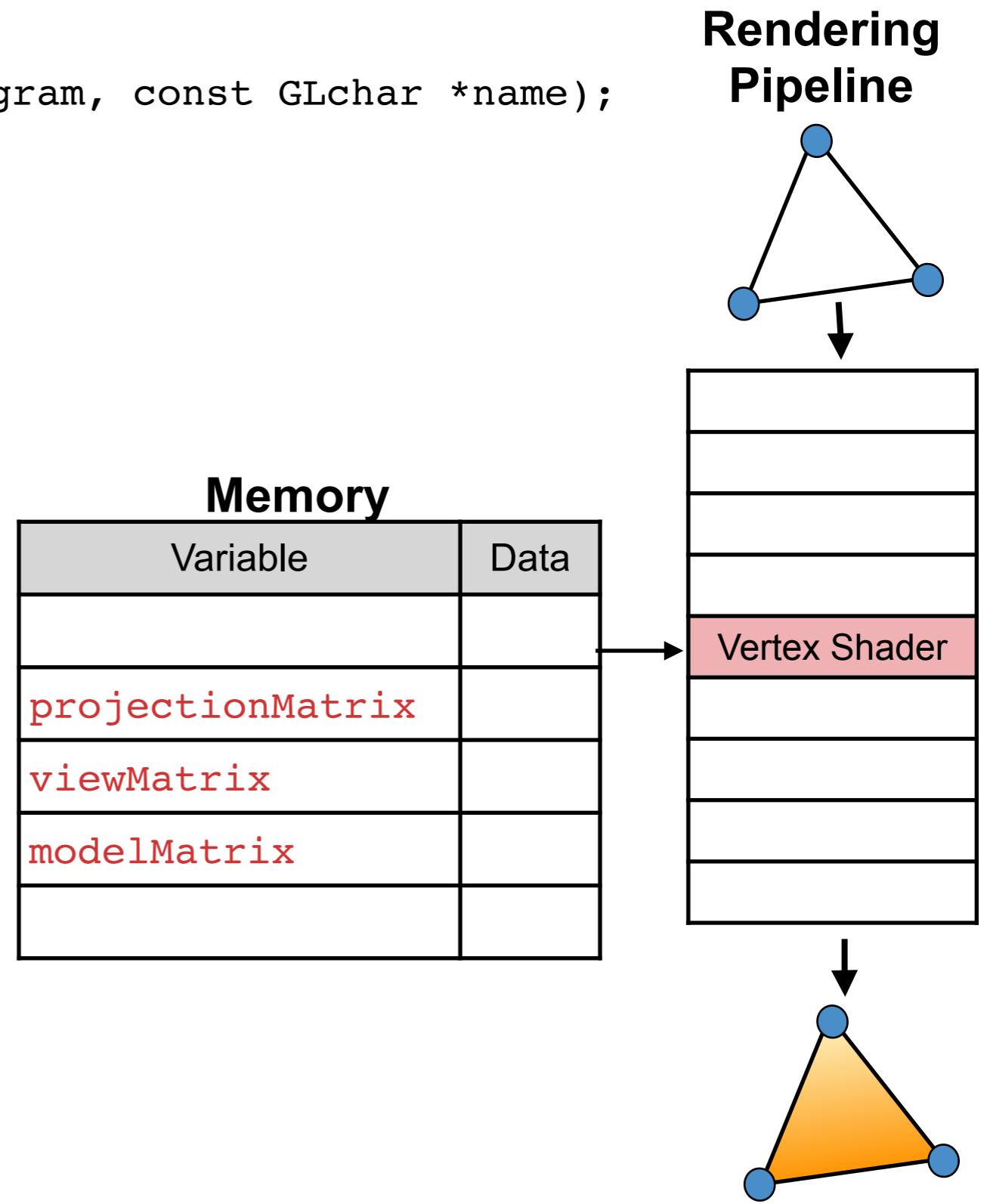
program: the shader
program variable

Uniform Variables

```
GLint glGetUniformLocation( GLuint program, const GLchar *name);
```

Returns the location of a uniform variable

- This function only creates the memory
- The data field remains empty



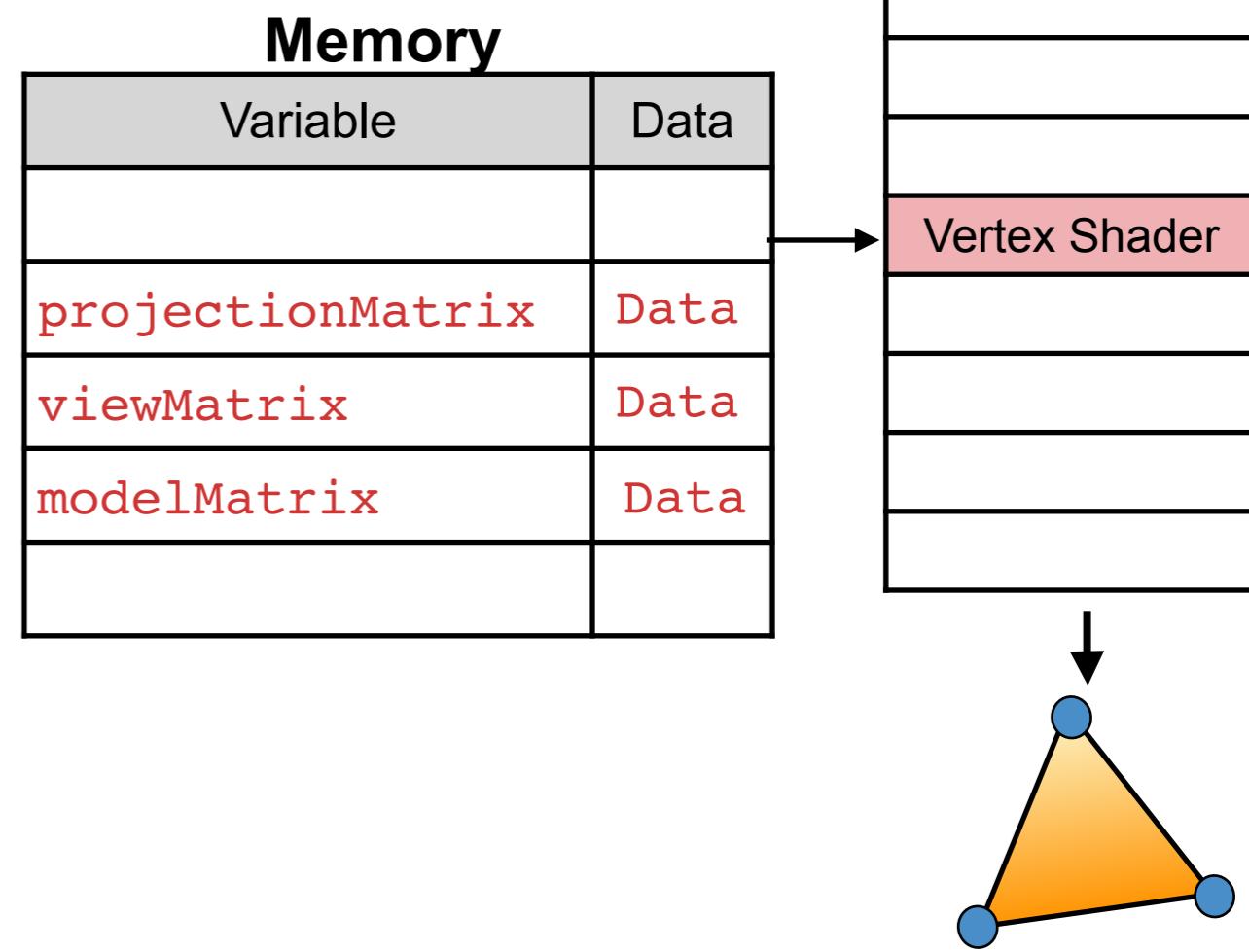
glUniformMatrix4fv

Copies the data into the graphics memory

```
void glUniformMatrix4fv( GLint location,  
GLsizei count,  
GLboolean transpose,  
const GLfloat *value);
```

Parameters:

- location: Specifies the location of the uniform value to be modified.
- count: Specifies the number of matrices that are to be modified.
- transpose: Must be GL_FALSE.
- value: Specifies a pointer to an array of count values that will be used to update the specified uniform variable.



Example



```
glUniformMatrix4fv(projectionMatrixLocation, 1, GL_FALSE,  
                    &projectionMatrix[0][0]);  
  
glUniformMatrix4fv(viewMatrixLocation, 1, GL_FALSE,  
                    &viewMatrix[0][0]);  
  
glUniformMatrix4fv(modelMatrixLocation, 1, GL_FALSE,  
                    &modelMatrix[0][0]);
```

Example and Structure

```
int main(int argc, const char * argv[])
```

```
{
```

```
    glUniformMatrix4fv(projectionMatrixLocation, 1, GL_FALSE,  
                        &projectionMatrix[0][0]);
```

```
[..also the others.]
```

```
while
```

```
    Clear the window
```

```
// Enable the shader program
```

```
glUseProgram(program);
```

```
    glBindVertexArray(vaoID[0]);
```

```
    modelMatrix = glm::translate(0.0f
```

```
    glUniformMatrix4fv(.....
```

```
    glDrawArrays(GL_TRIANGLE_STRIP, 0, 16);
```

```
    glBindVertexArray(vaoID[1]);
```

```
    modelMatrix = glm::translate(5, 9f
```

```
    glUniformMatrix4fv(.....
```

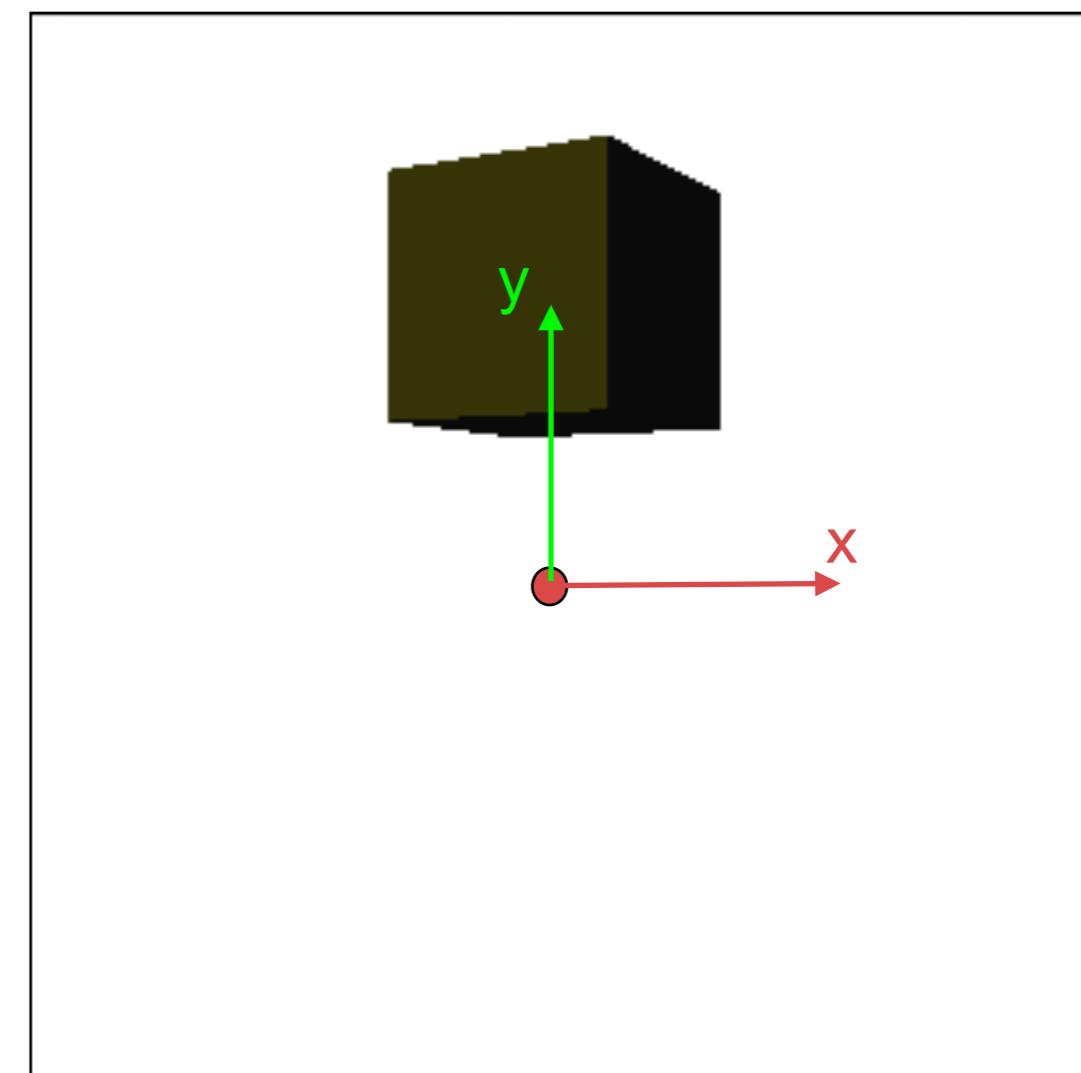
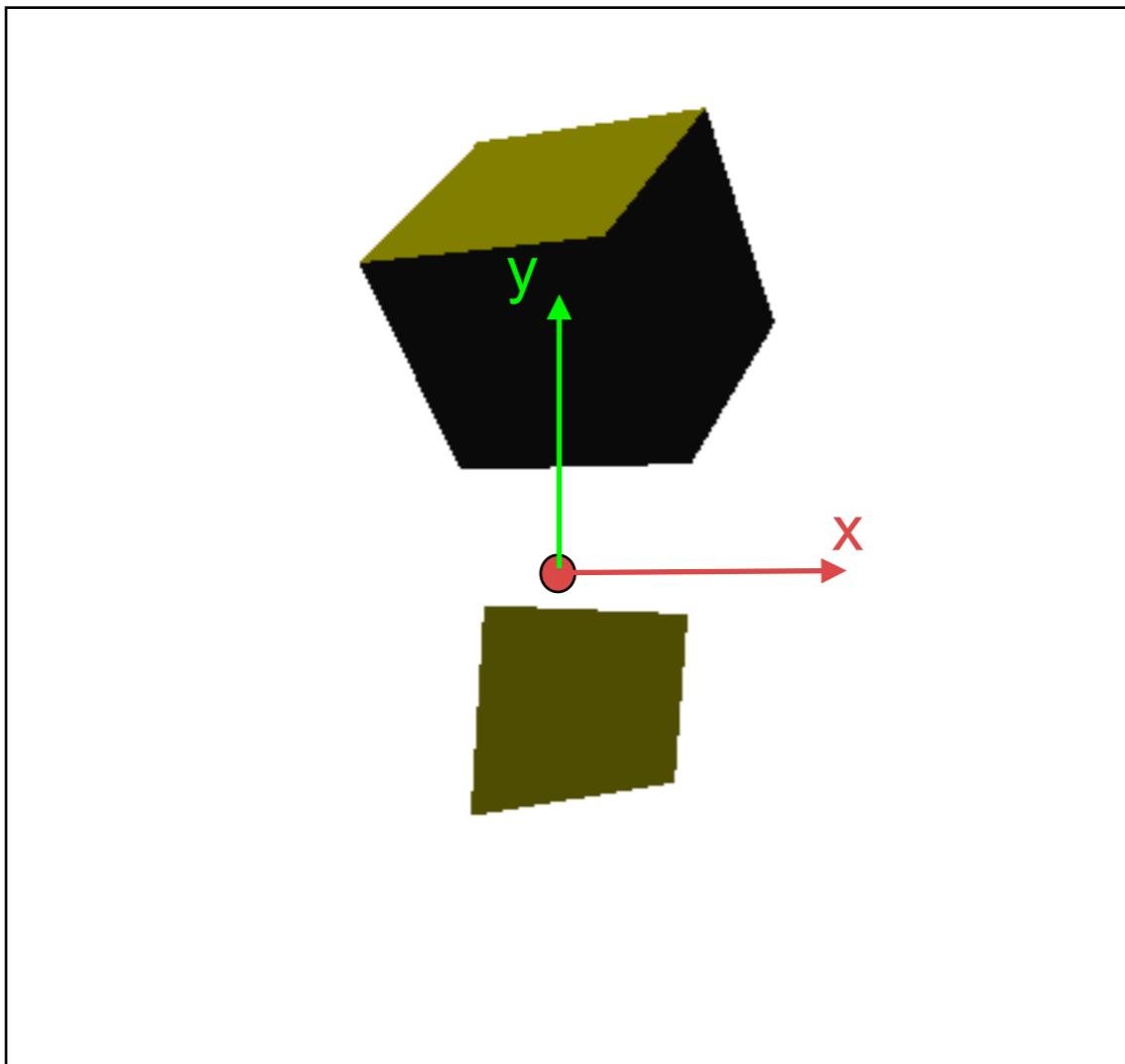
```
    glDrawArrays(GL_TRIANGLE, 0, 16);
```

```
    glUseProgram(0);
```

```
Swap buffers
```

```
}
```

A lot of things to remember, but we will practice on Thursday



Questions ?

Thank you!

Questions

Rafael Radkowski, Ph.D.
Iowa State University
Virtual Reality Applications Center
1620 Howe Hall
Ames, Iowa 50011, USA
+1 515.294.5580
+1 515.294.5530(fax)
rafael@iastate.edu
<http://arlabs.me.iastate.edu>



IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY