CSE4203: Computer Graphics

Chapter – 7 (part - A)

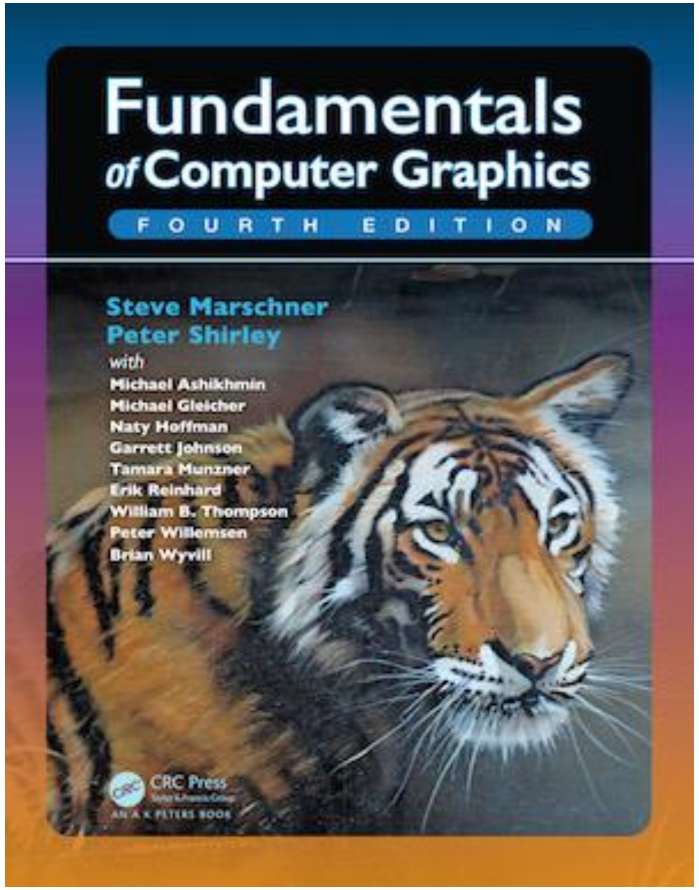
Viewing

Mohammad Imrul Jubair

Outline

– Image-order and object-render rendering
– Viewing transformation
– Viewport transformation
– Orthographic projection transformation

Credit



CS4620: Introduction to Computer Graphics

Cornell University

Instructor: Steve Marschner

http://www.cs.cornell.edu/courses/cs4620/2019fa/

Rendering Techniques (1/2)

- One of the basic tasks of computer graphics is rendering 3D objects:
  – taking a scene, or model, composed of many geometric objects arranged in 3D space
  – producing a 2D image that shows the objects as viewed
  – from a particular viewpoint.

Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Rendering Techniques (2/2)

1. Image-order rendering: iterate over the pixels in the image to be produced, rather than the elements in the scene to be rendered.
2. object-order rendering: that iterate over the elements in the scene to be rendered, rather than the pixels in the image to be produced.

Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Image-order Rendering (1/2)

- Image-order rendering:
  - ***Ray-tracing:***

    Each pixel is considered in turn, and for each pixel
    - All the objects that influence it are found
    - and the pixel value is computed.
      - in Chapter 4

Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Object-order Rendering (1/2)

- Object-order rendering:
  - ***Viewing Transformation:***

    Each object is considered in turn, and for each object:
    - All the pixels that it influences are found and updated

Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Object-order Rendering (2/2)

- **Viewing Transformation** (this chapter):
  - The inverse of the previous process.
  - How to use ***matrix transformations*** to express any parallel or perspective view.
  - These transformations:
    - Project 3D points in the scene (world space) to 2D points in the image (image space)

Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

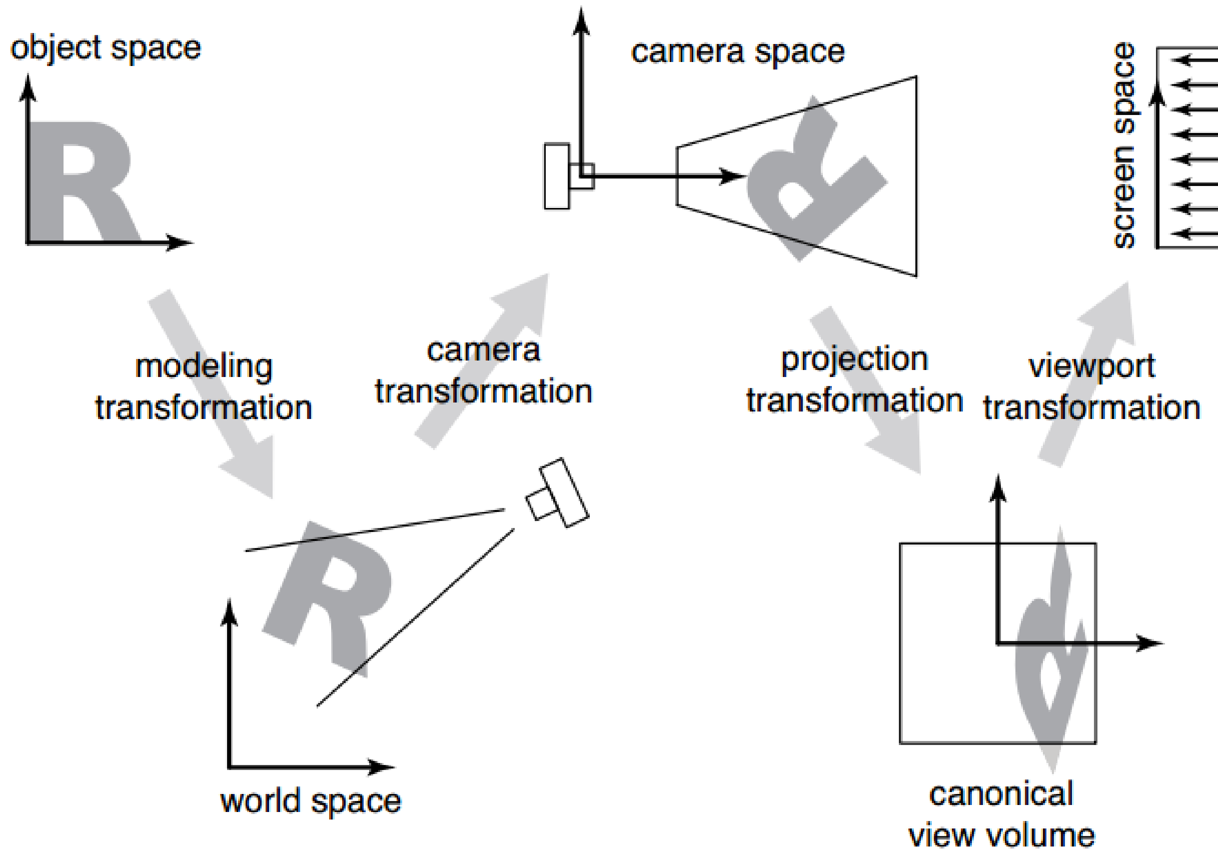
Object space vs World space vs Camera space

– Object space

– World space

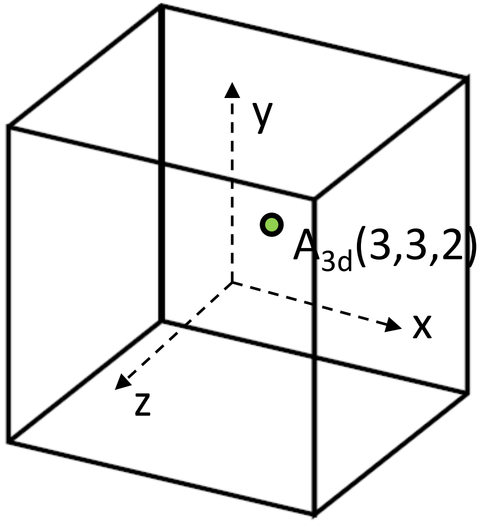
– Camera space

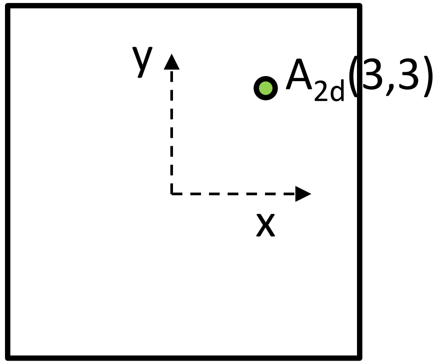
Viewing Transformation Sequences (1/1)



Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Viewport Transformation (1/19)

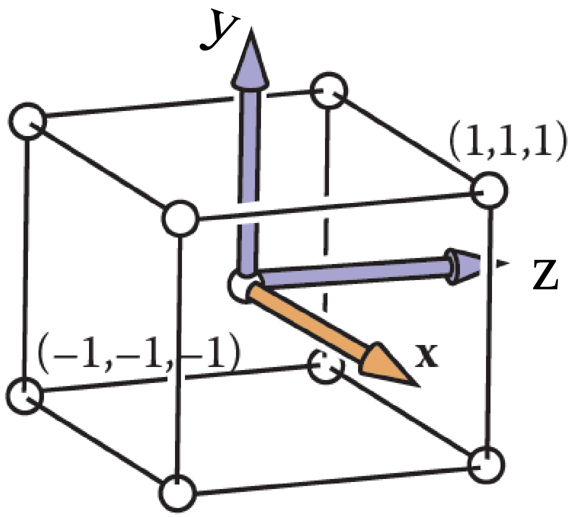




- Projection: Ignoring the *z*-coordinate

Viewport Transformation (2/19)

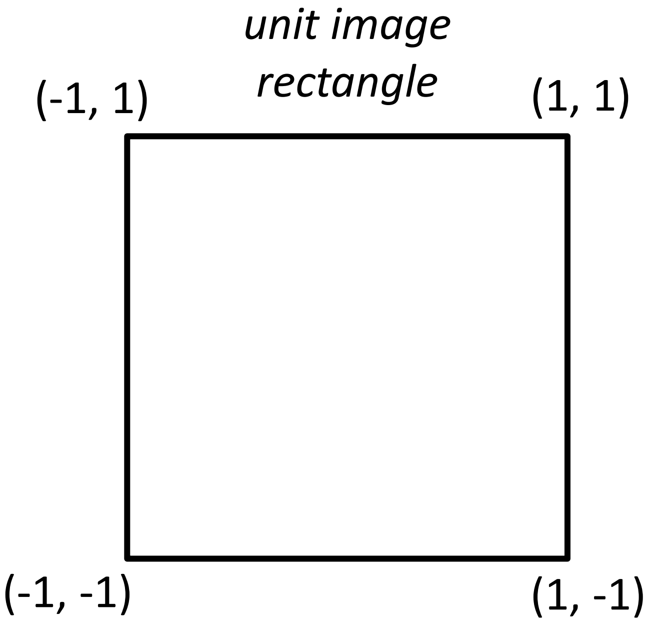
- Canonical View Volume: $(x,y,z) \in [-1, 1]^3$
  - We will assume that the model to be drawn are completely inside the canonical view vol.



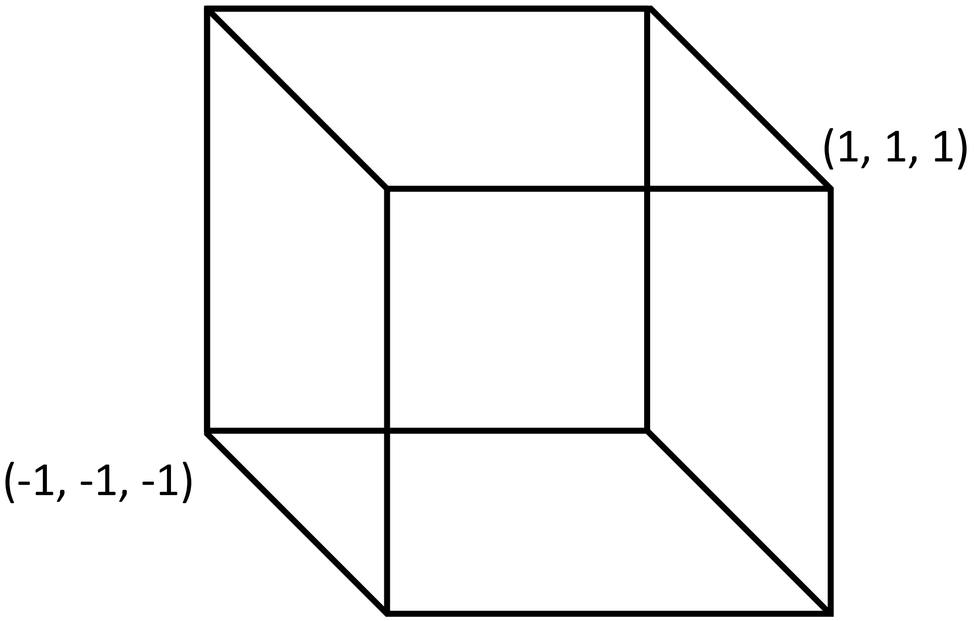
$(x,y,z) \in [-1, 1]^3$

Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Viewport Transformation (4/19)



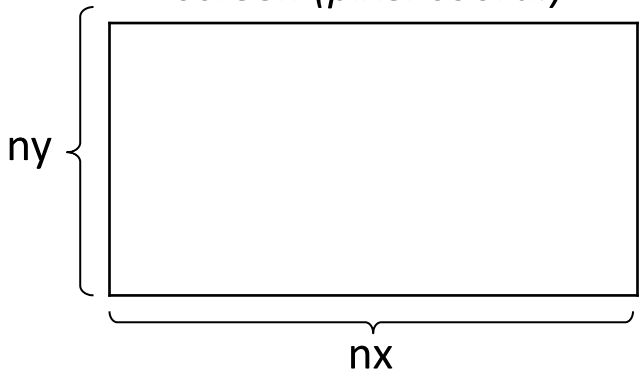
$(x,y) \in [-1, 1]^2$

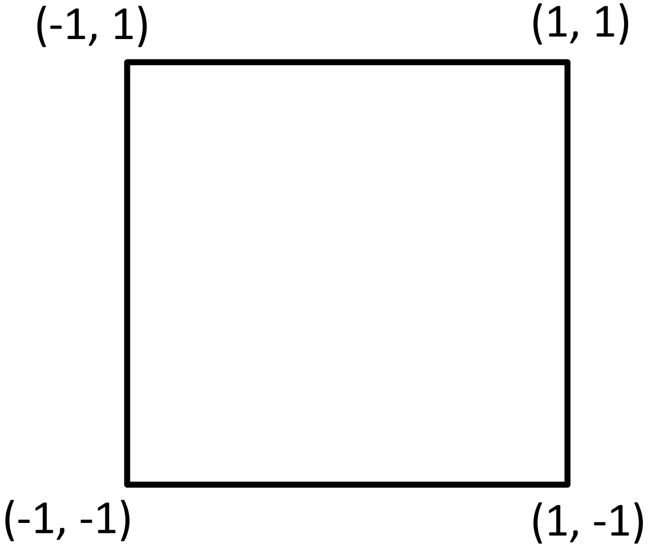


$(x,y,z) \in [-1, 1]^3$

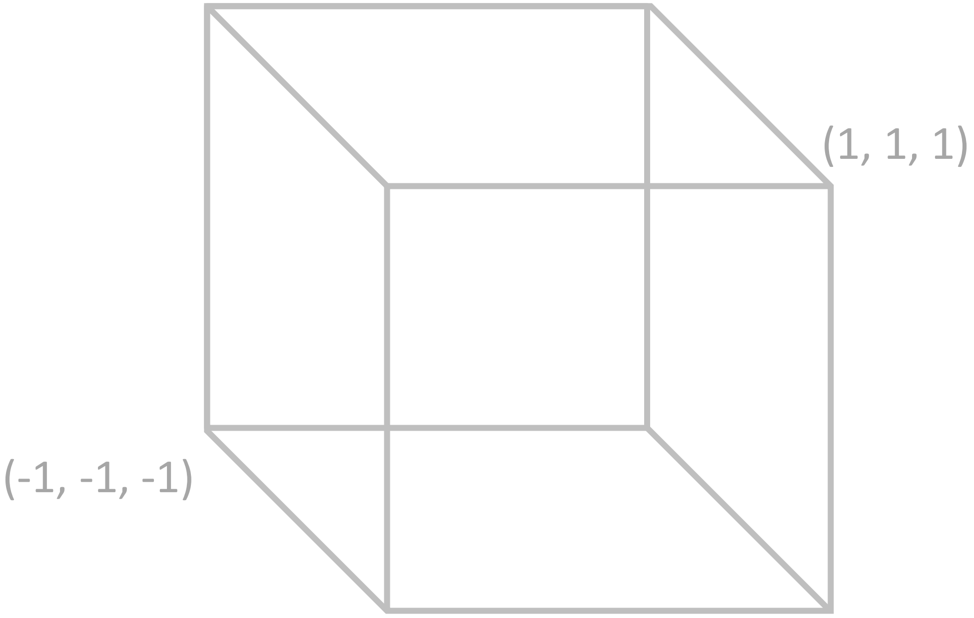
Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Viewport Transformation (5/19)





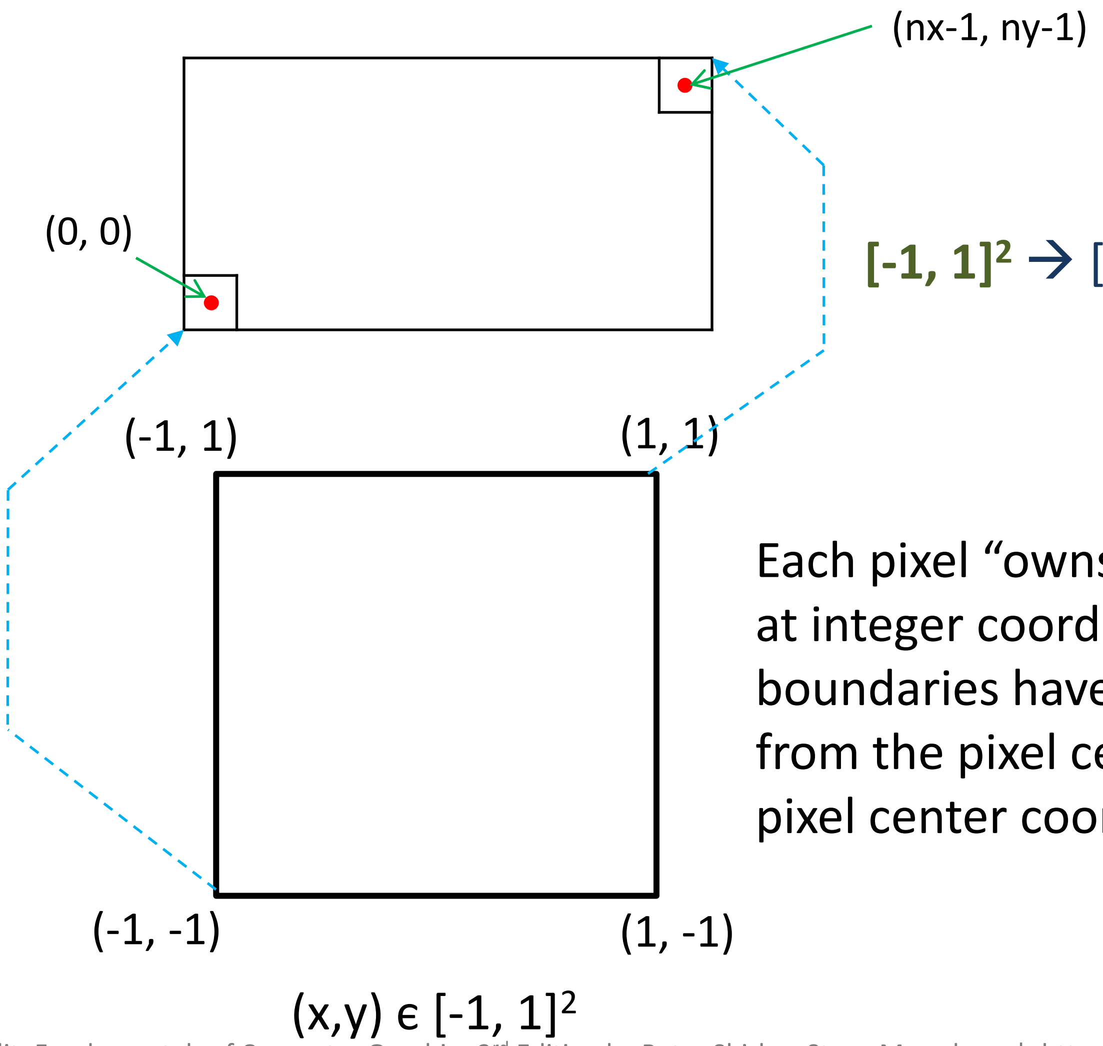
$(x,y) \in [-1, 1]^2$



$(x,y,z) \in [-1, 1]^3$

Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Viewport Transformation (7/19)

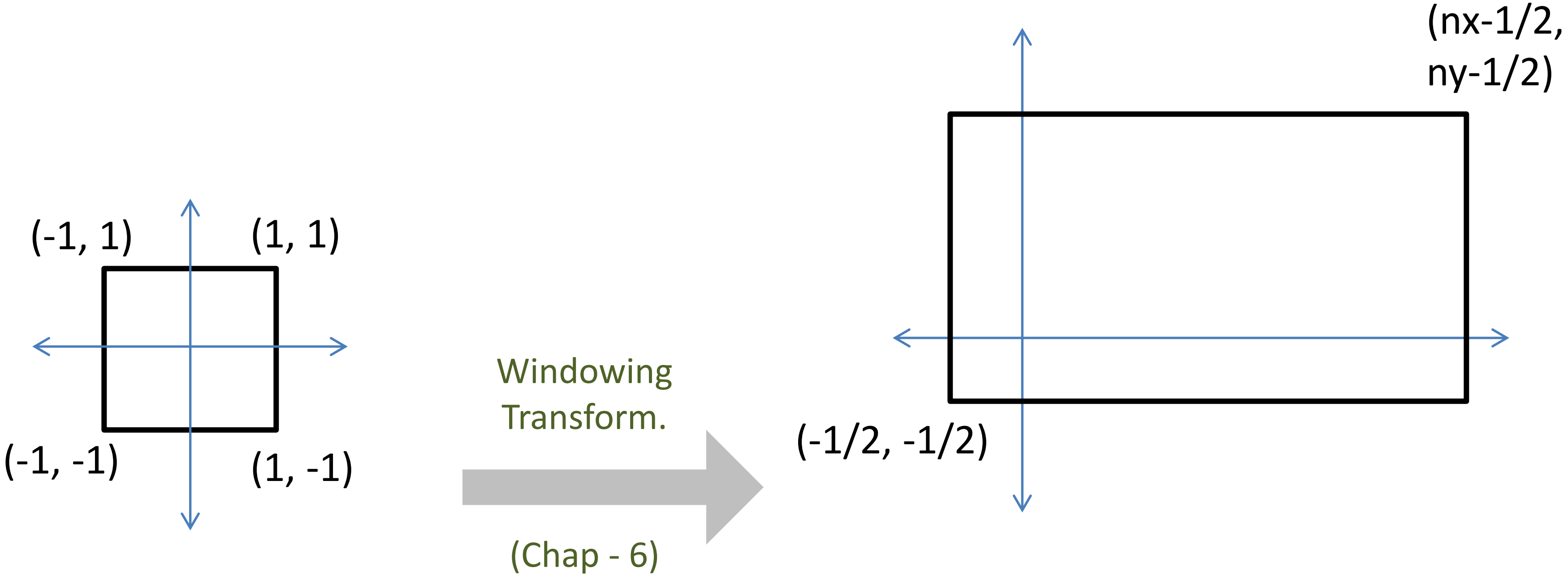


$[-1, 1]^2$ → $[-0.5, nx-0.5] \times [-0.5, ny-0.5]$

Each pixel "owns" a unit square centered at integer coordinates; the image boundaries have a half unit overshoot from the pixel centers; and the smallest pixel center coordinates are (0, 0).

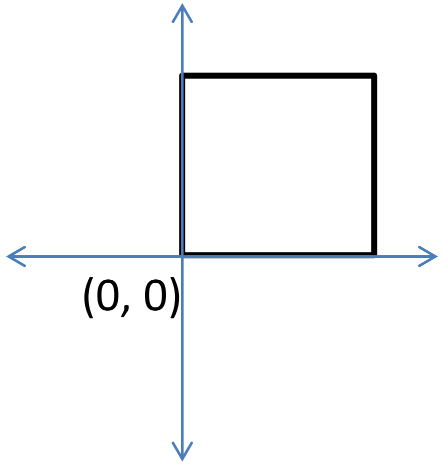
Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

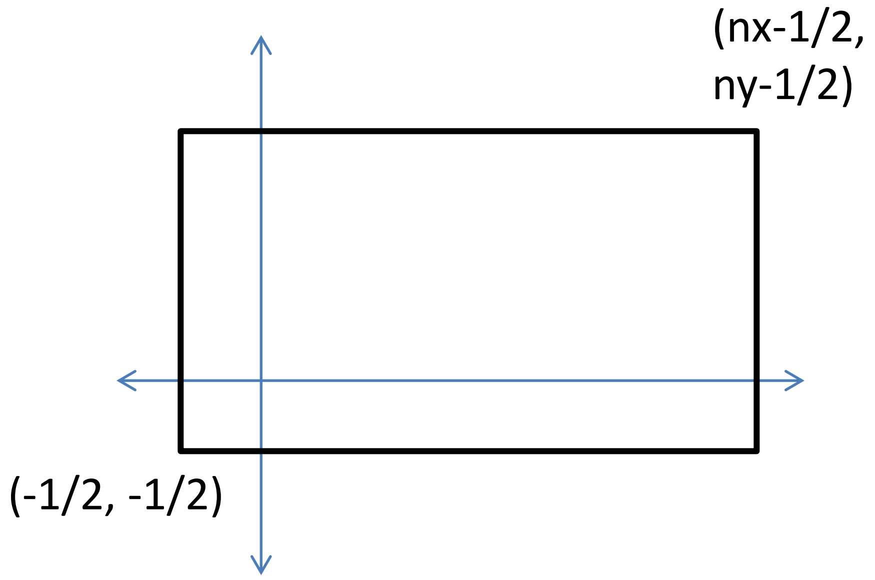
Viewport Transformation (8/19)



Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

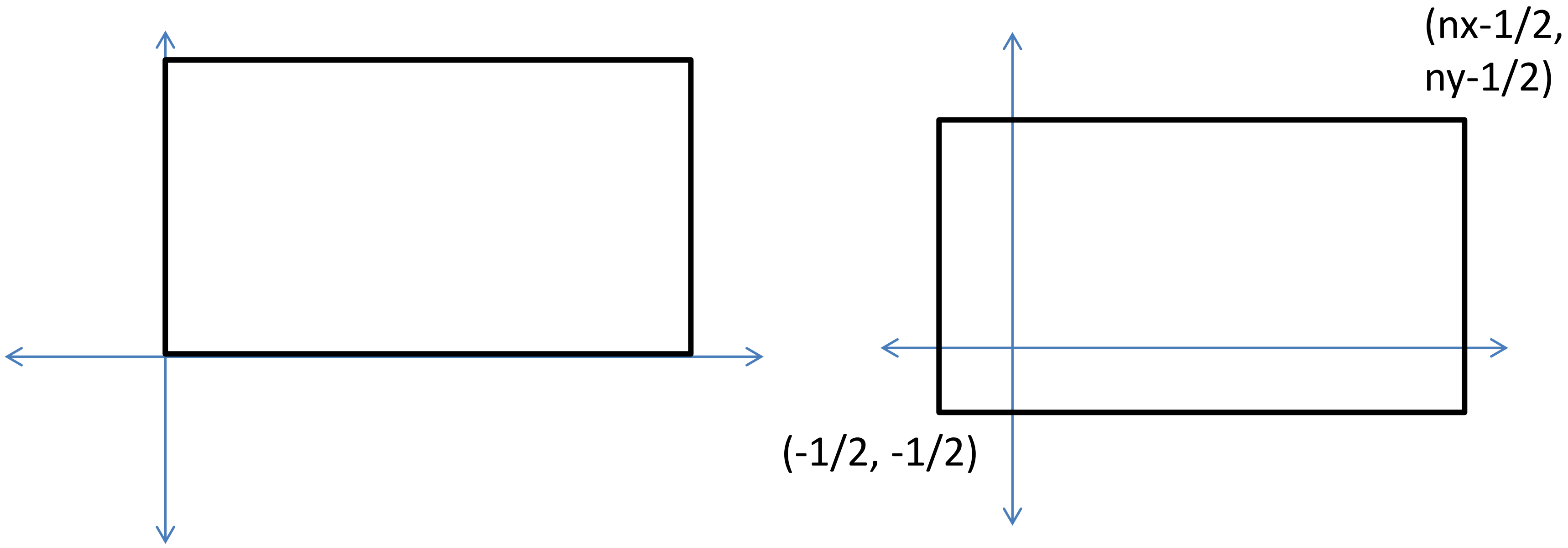
Viewport Transformation (9/19)





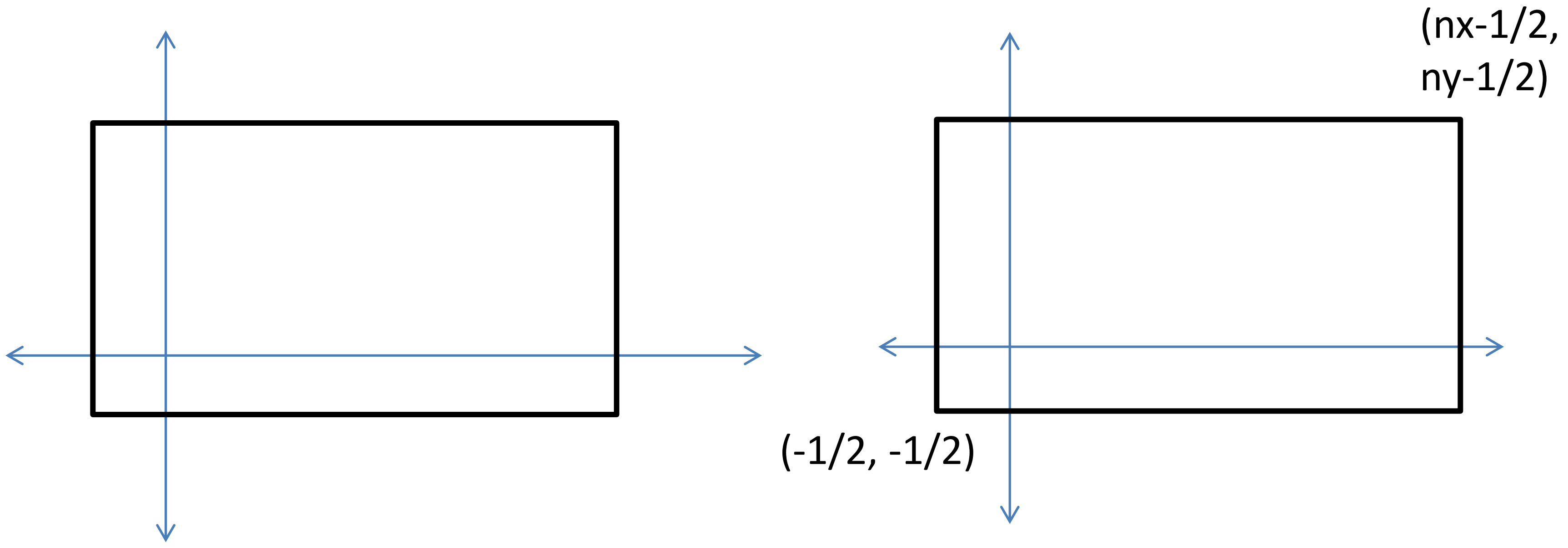
T(1, 1)

Viewport Transformation (10/19)



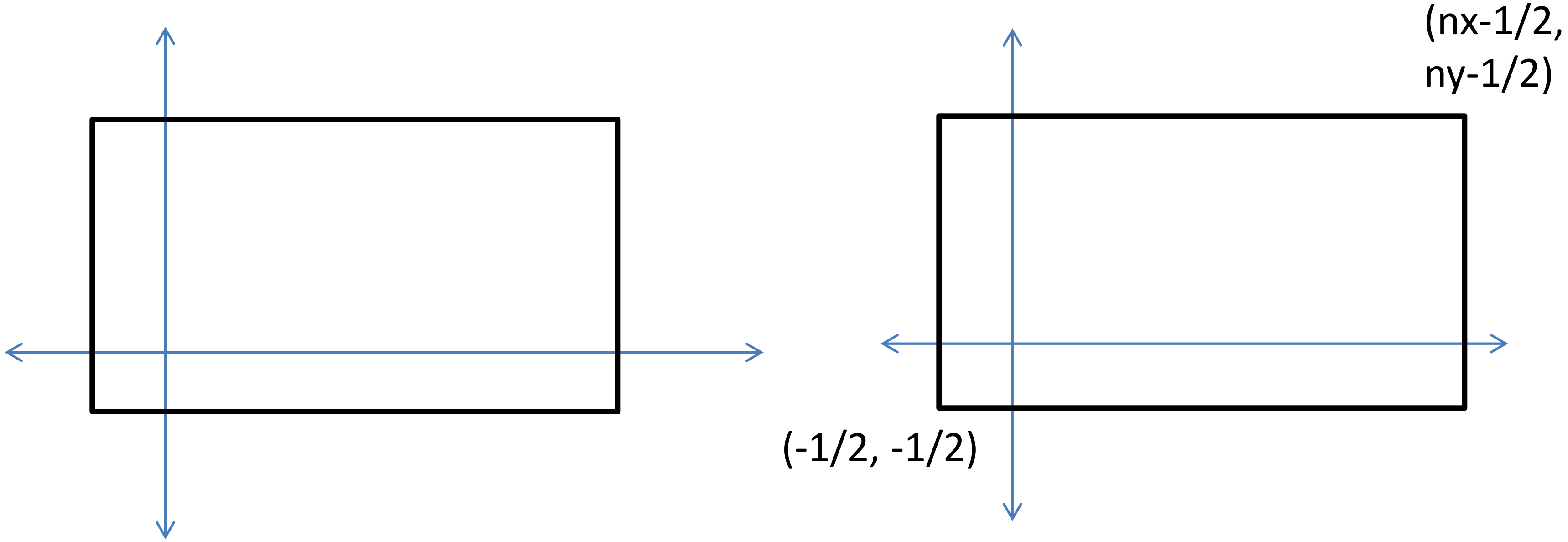
T(1, 1) → S(nx/2, ny/2)

Viewport Transformation (11/19)



T(1, 1) → S(nx/2, ny/2) → T(-1/2, -1/2)

Viewport Transformation (12/19)



T(1, 1) → S(nx/2, ny/2) → T(-1/2, -1/2)

M_{vp} = T(-1/2, -1/2) * S(nx/2, ny/2) * T(1,1)

Viewport Transformation (15/19)

M_{vp} = T(-1/2, -1/2) * S(nx/2, ny/2) * T(1, 1)

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

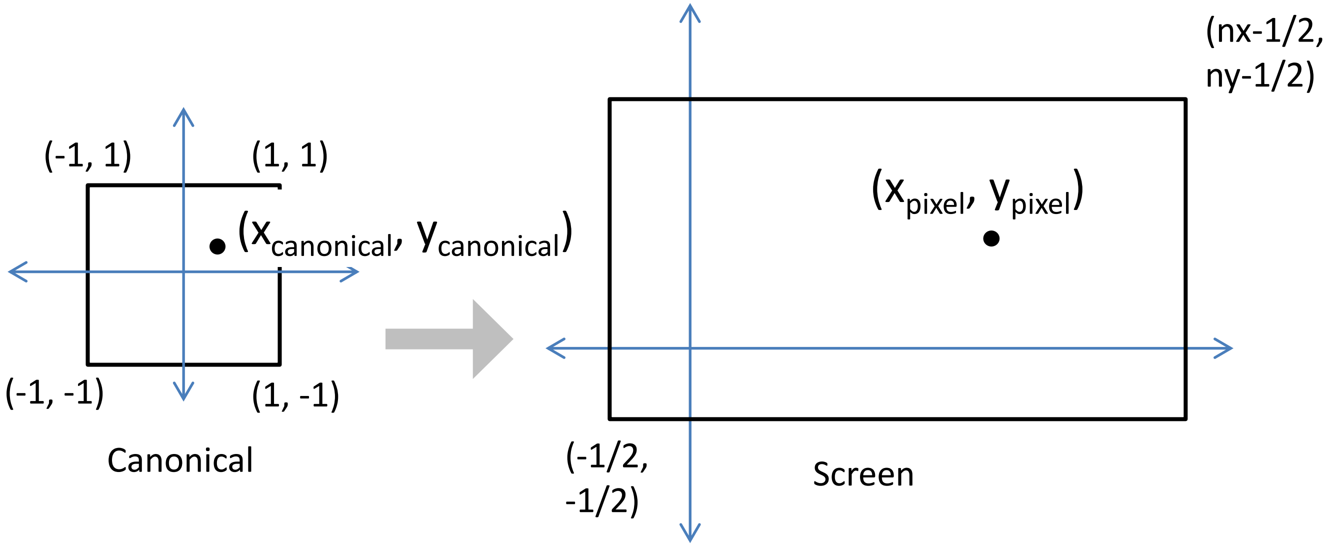
Q: Do matrix multiplication and check

Viewport Transformation (16/19)

M_{vp} = T(-1/2, -1/2) * S(nx/2, ny/2) * T(1, 1)

This is similar to windowing transform. (Chap - 6)

$$\begin{bmatrix} x_{\text{pixel}} \\ y_{\text{pixel}} \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{n_x}{2} & 0 & \frac{n_x-1}{2} \\ 0 & \frac{n_y}{2} & \frac{n_y-1}{2} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{\text{canonical}} \\ y_{\text{canonical}} \\ 1 \end{bmatrix}$$



Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Viewport Transformation (18/19)

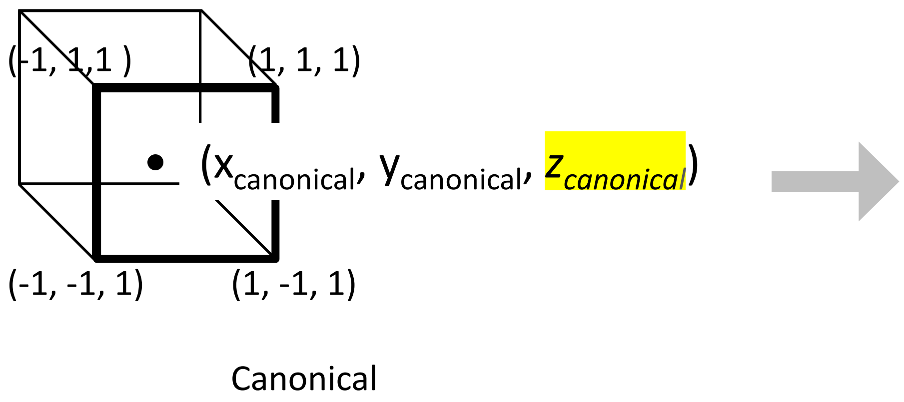
$$\begin{bmatrix} \frac{n_x}{2} & 0 & \frac{n_x-1}{2} \\ 0 & \frac{n_y}{2} & \frac{n_y-1}{2} \\ 0 & 0 & 1 \end{bmatrix}$$

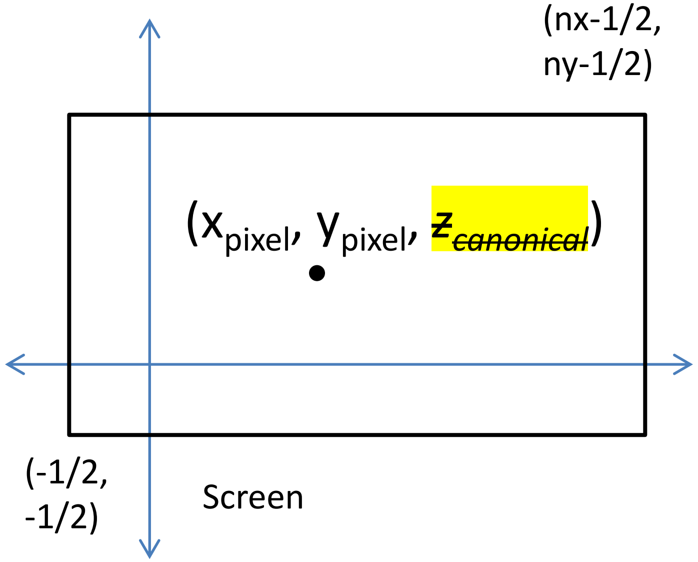
$$M_{\text{vp}} = \begin{bmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x-1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y-1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Viewport Transformation (19/19)

[carry along the z-coordinate without changing it]

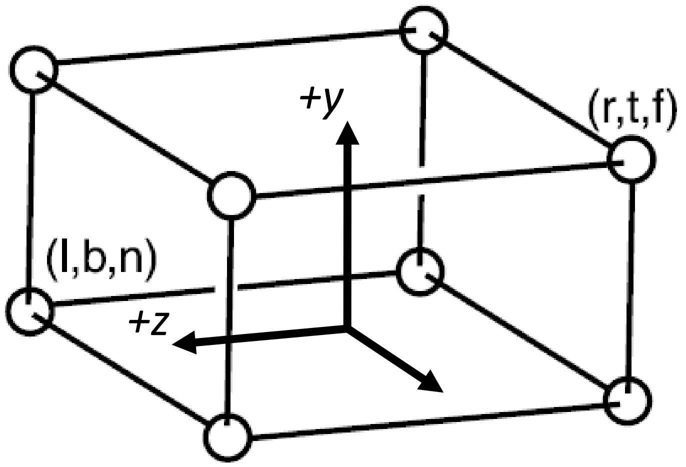
$$\begin{bmatrix} x_{\text{pixel}} \\ y_{\text{pixel}} \\ z_{\text{canonical}} \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x - 1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y - 1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{\text{canonical}} \\ y_{\text{canonical}} \\ z_{\text{canonical}} \\ 1 \end{bmatrix}$$





Orthographic Projection Transformation (1/1)

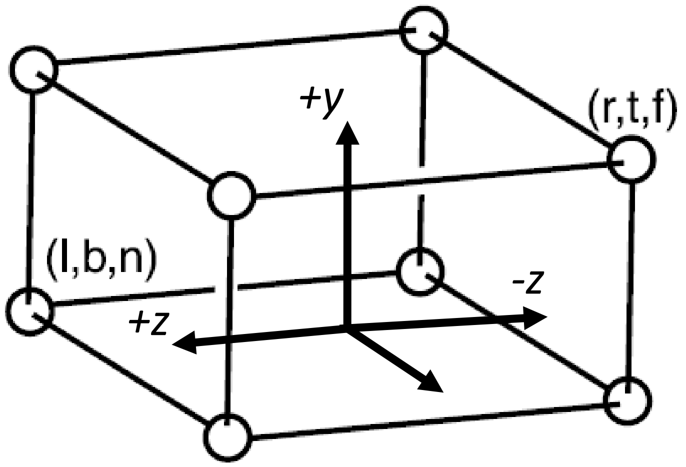
- What if we want to render geometry in some region other than canonical view vol.?



Orthographic View Volume (1/3)

- We’ll name the coordinates of its sides so that the view volume is ***[l, r] × [b, t] × [f, n]***
  - View direction: *looking along −z*
  - Orientation: *+y up*

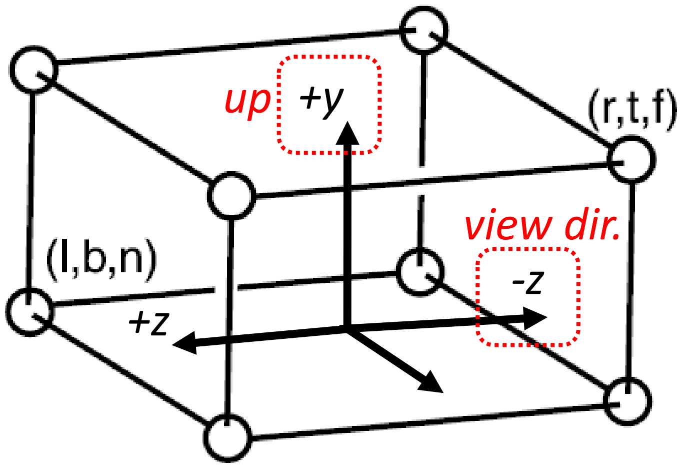
    - *x = l ≡ left plane,*
    - *x = r ≡ right plane,*
    - *y = b ≡ bottom plane,*
    - *y = t ≡ top plane,*
    - *z = n ≡ near plane,*
    - *z = f ≡ far plane.*



Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

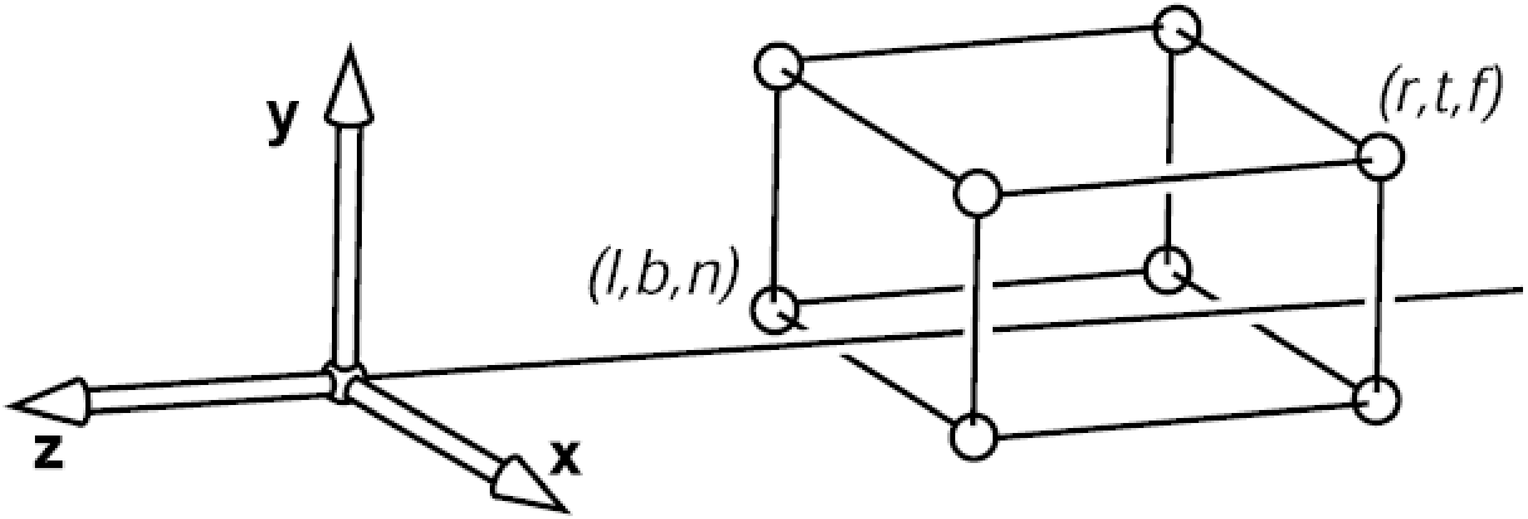
Orthographic View Volume (2/3)

- Looking along the *minus z-axis* with his head pointing in the *positive y-direction.*
  - View direction: *looking along −z*
  - Orientation: *+y up*
- *But, this is unintuitive!*



Orthographic View Volume (3/3)

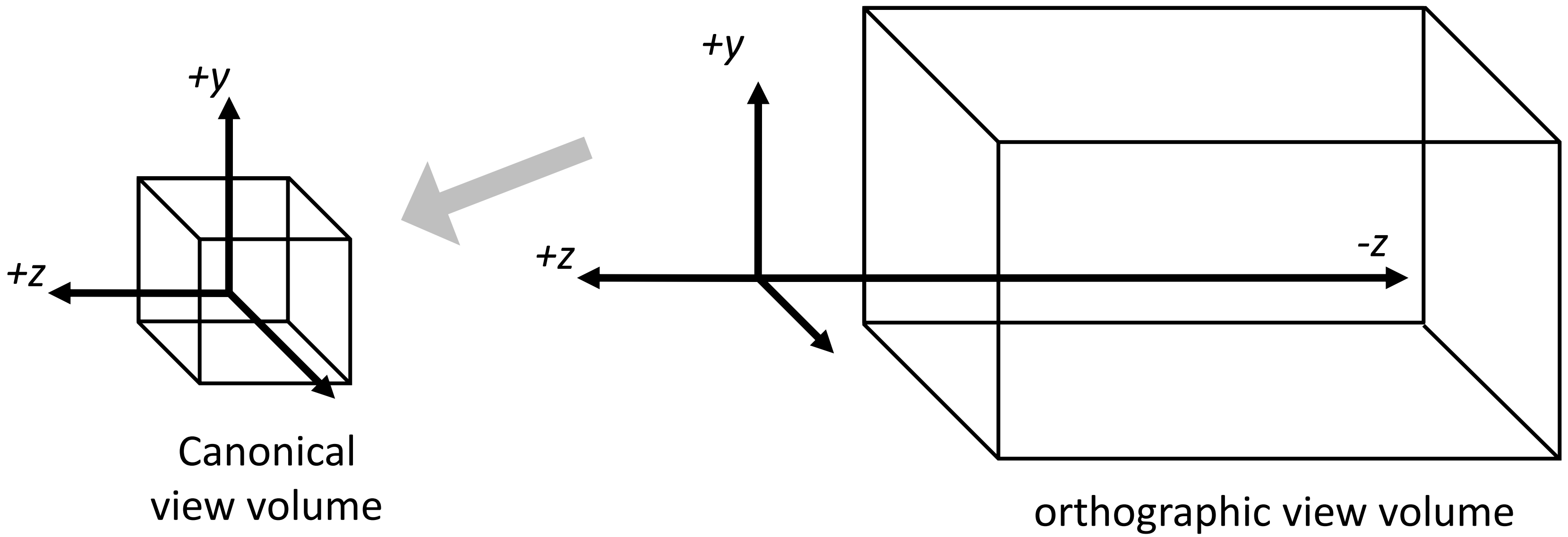
- If entire orthographic view volume has **negative *z*** then $n > f$.
  - *z = n plane is closer*



Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Orthographic to Canonical View Volume (1/3)

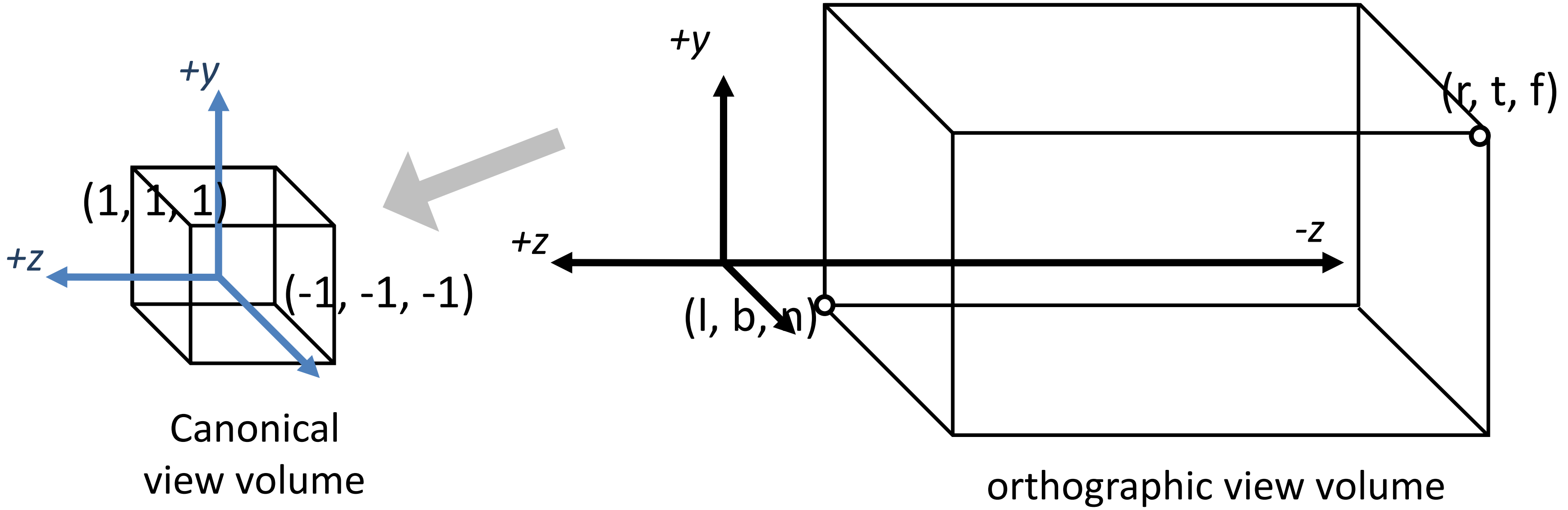
- Transform from orthographic view volume to the canonical view volume
  - We need to apply *windowing transformation* (just like before!)



Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Orthographic to Canonical View Volume (2/3)

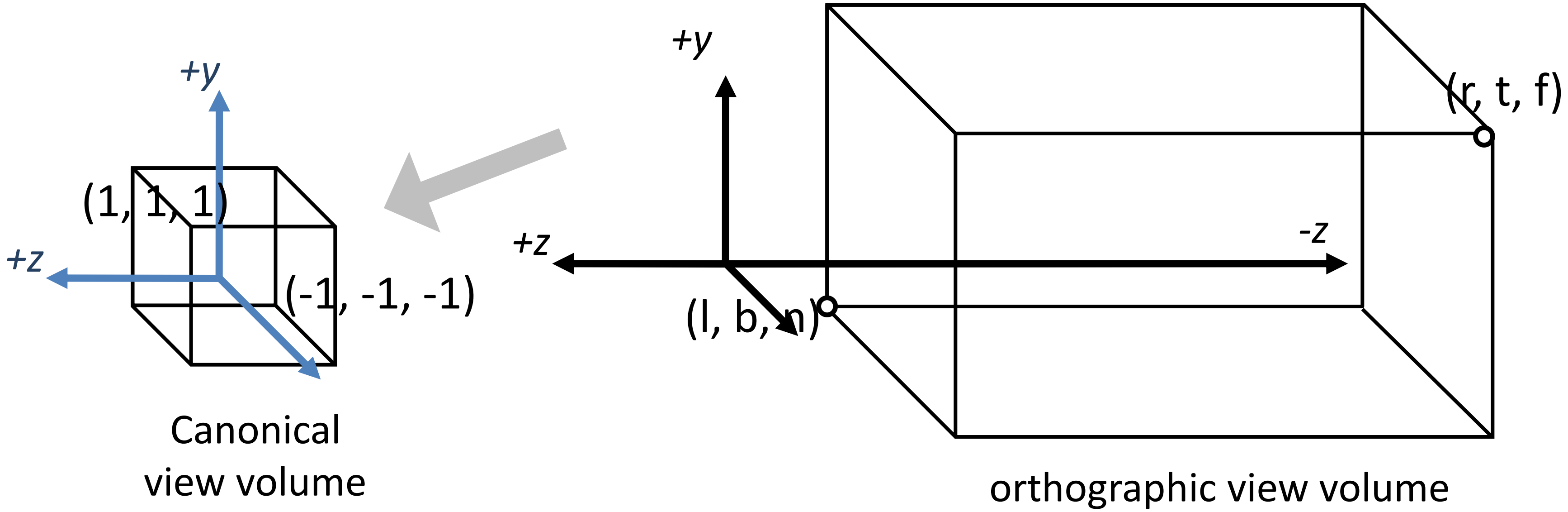
$$\mathbf{M}_{\text{orth}} = \begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Orthographic to Canonical View Volume (3/3)

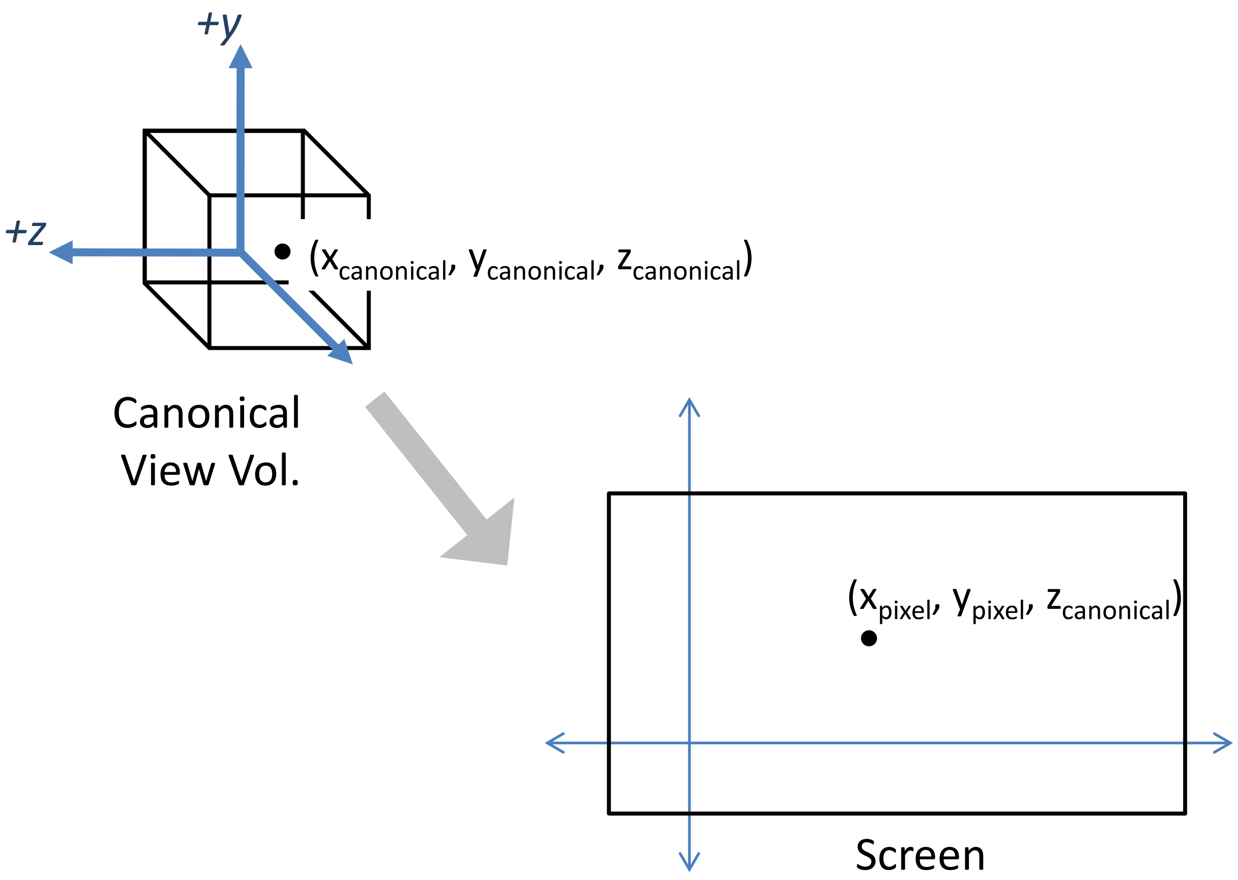
$$\mathbf{M}_{\mathrm{orth}} = \begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Q: How can we get this matrix?
Help: Chap 6 (Windowing Transformation) and M_{vp}

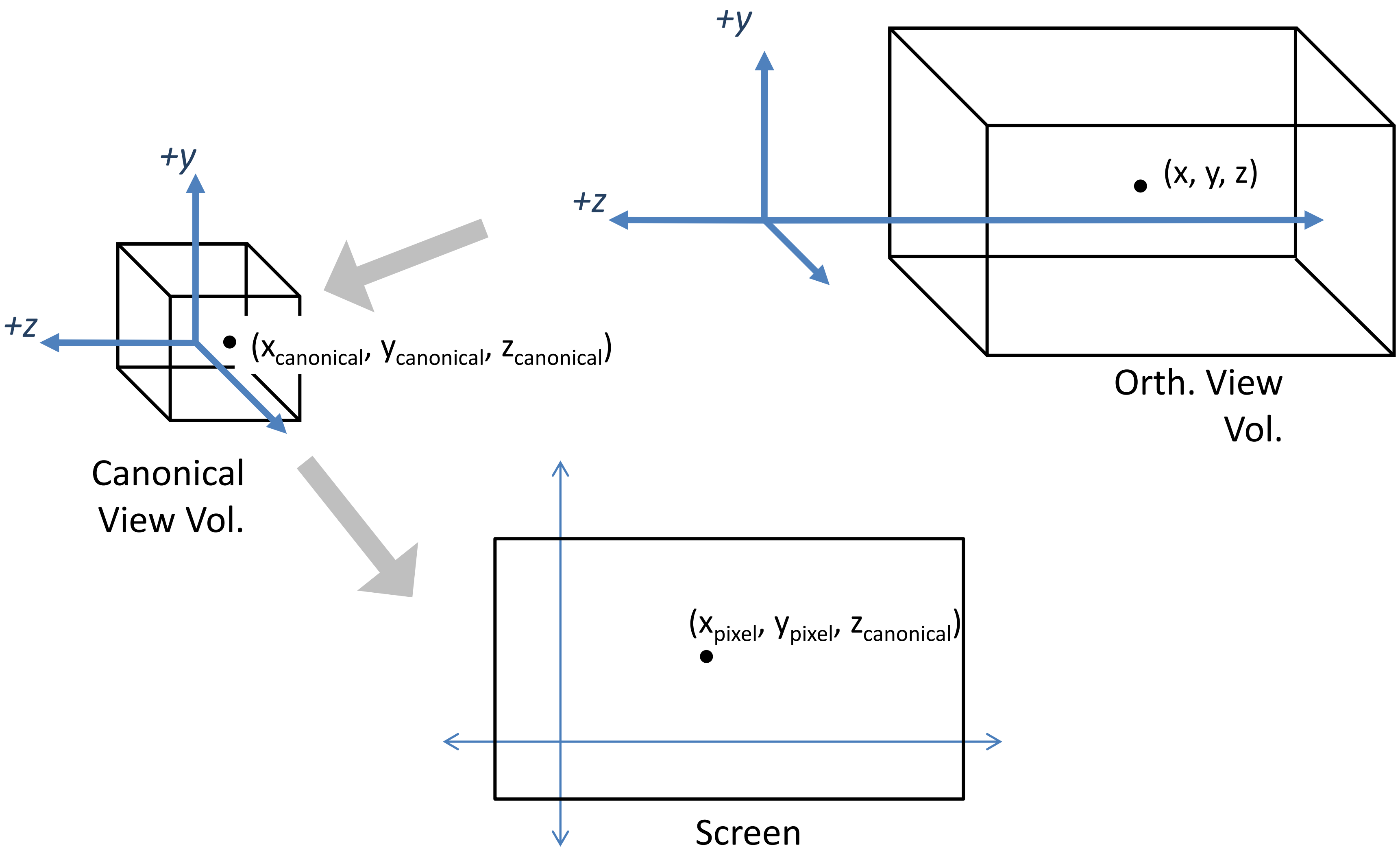


Credit: Fundamentals of Computer Graphics 3rd Edition by Peter Shirley, Steve Marschner | http://www.cs.cornell.edu/courses/cs4620/2019fa/

Orthographic → Canonical → Screen (1/5)

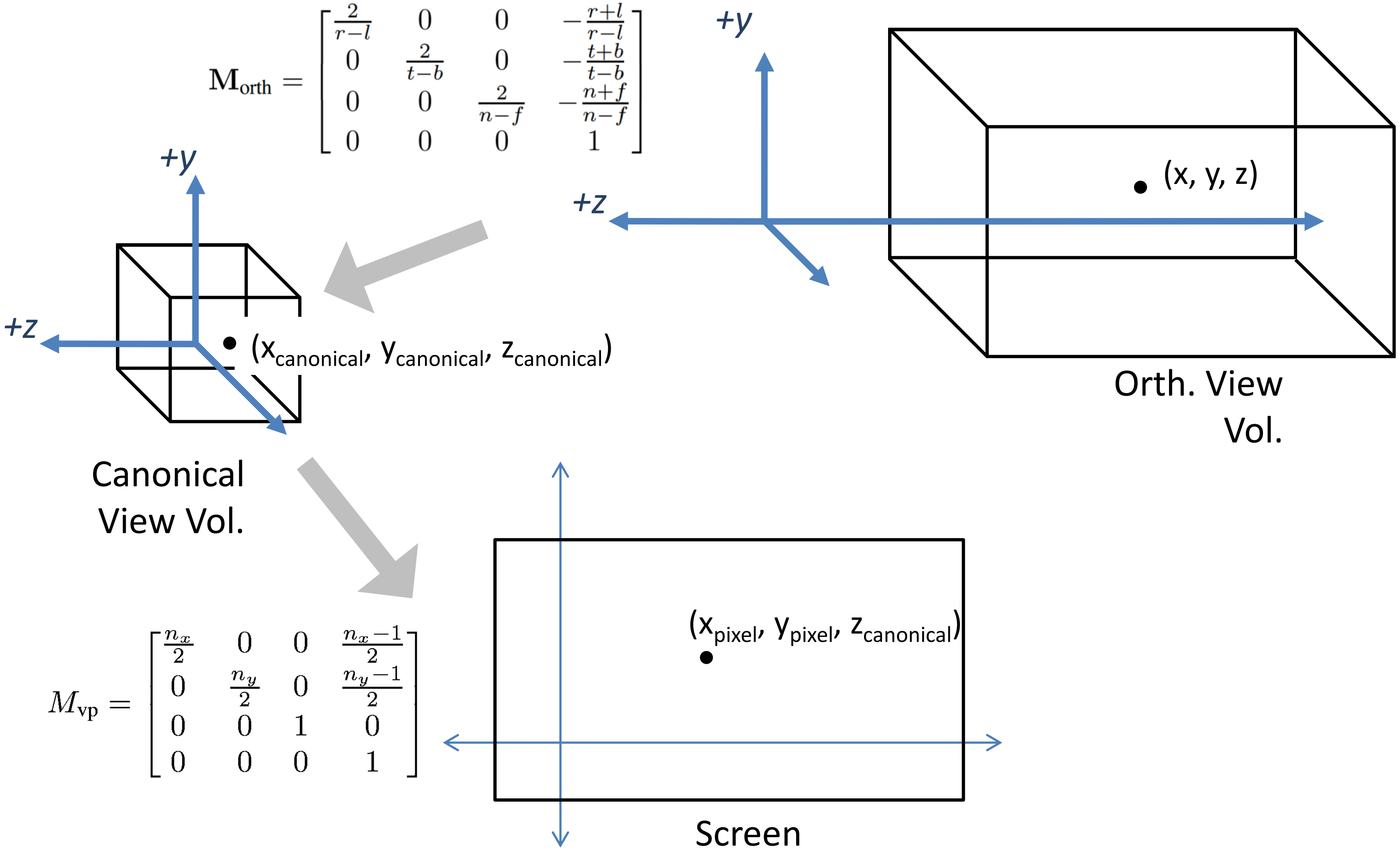


Orthographic → Canonical → Screen (2/5)



Orthographic → Canonical → Screen (3/5)

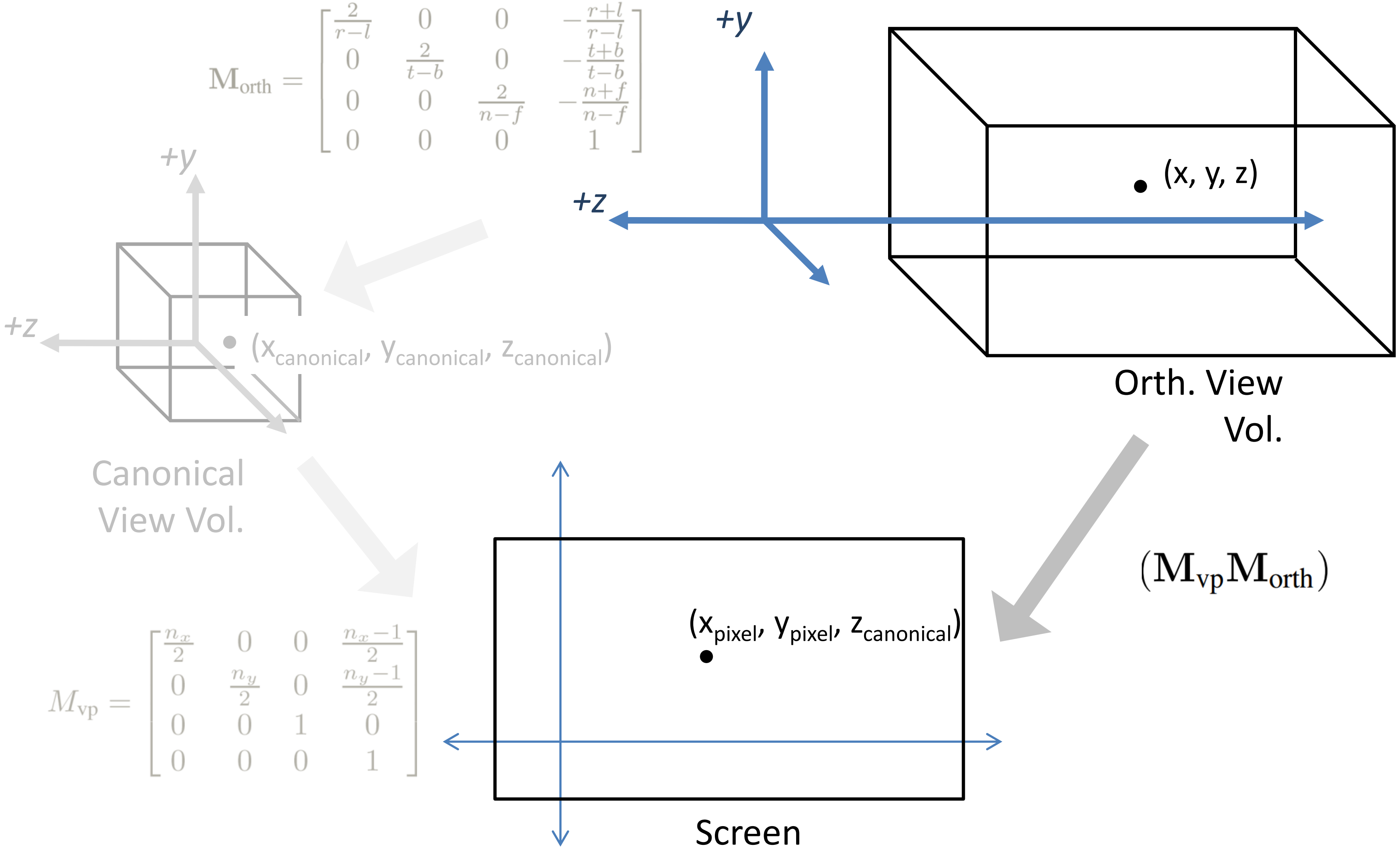
$$\mathrm{M}_{\text{orth}} = \begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



$$M_{\text{vp}} = \begin{bmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x-1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y-1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Orthographic → Canonical → Screen (4/5)

$$\mathrm{M}_{\mathrm{orth}} = \begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

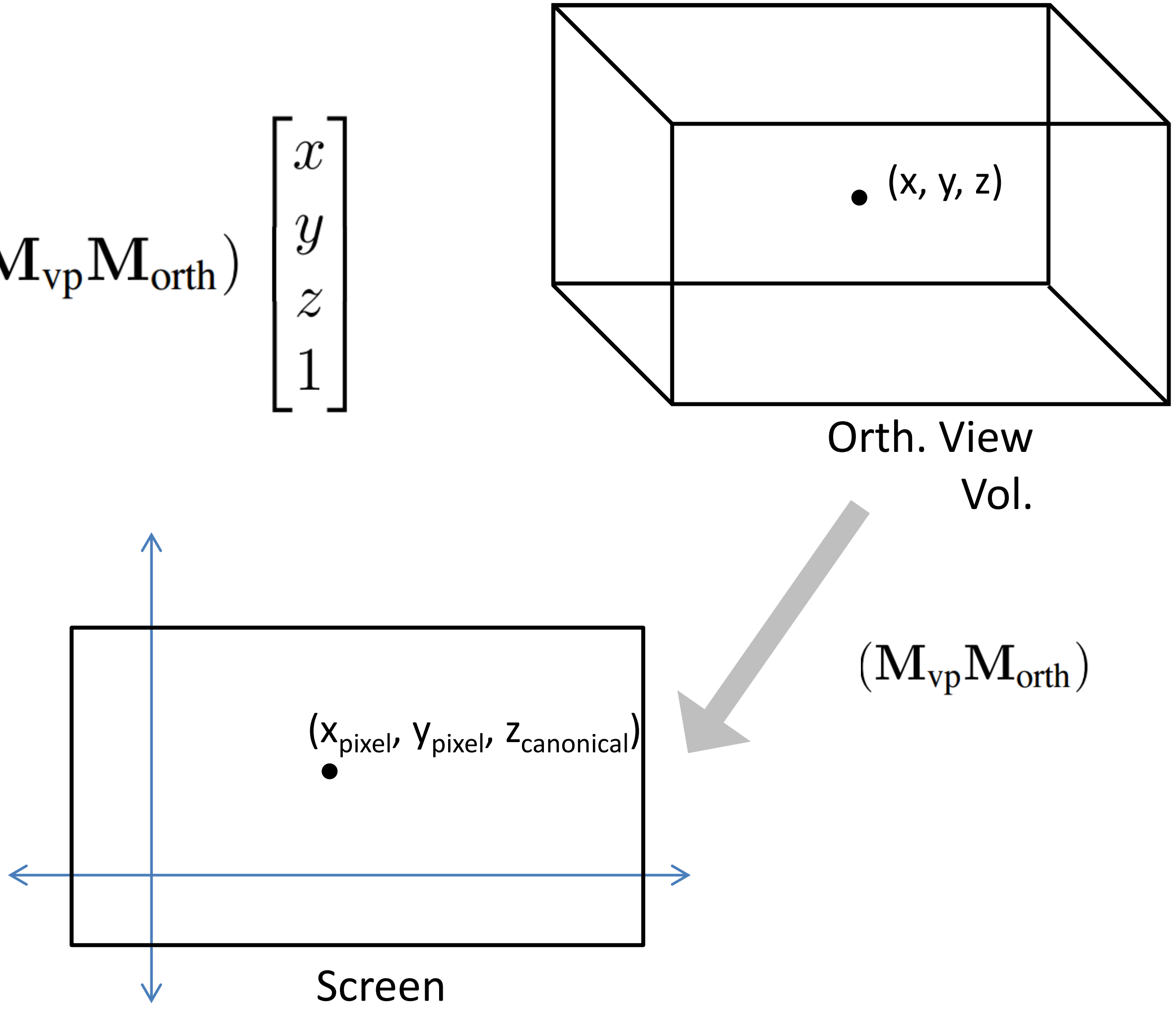


$$(\mathbf{M}_{\mathrm{vp}}\mathbf{M}_{\mathrm{orth}})$$

$$M_{\mathrm{vp}} = \begin{bmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x-1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y-1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Orthographic → Canonical → Screen (5/5)

$$\begin{bmatrix} x_{\text{pixel}} \\ y_{\text{pixel}} \\ z_{\text{canonical}} \\ 1 \end{bmatrix} = (\mathbf{M}_{\text{vp}}\mathbf{M}_{\text{orth}}) \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$



Code: *Orthographic to Screen* (1/1)

Drawing many 3D lines with endpoints a_i and b_i:

```
Construct M_vp
Construct M_orth
M = M_vp*M_orth

for each line segment (a_i, b_i) do:
      p = M*a_i
      q = M*b_i
      drawline (x_p, y_p, x_q, y_q)
```

Practice Problem - 1

Transform a 3D line AB from an *orthographic view volume* to a *viewport* of size 128 x 96. Vertices of the line are A(-1, -3, -5) and B(2, 4, -6). The orthographic view volume has the following setup:

$$l = -4,\ r = 4,\ b = -4,\ t = 4,\ n = -4,\ f = -8$$

You must -

a. Determine the transformation matrix *M*.
b. Multiply *M* with the vertices of the line and determine the position of vertices on viewport.

Practice Problem – 1 (Sol.)

$$M_{\text{vp}} = \begin{bmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x - 1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y - 1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

nx = 128
ny = 96

$$\mathbf{M}_{\text{orth}} = \begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

l = - 4, r = 4,
b = - 4, t = 4,
n = - 4, f = - 8

Practice Problem – 1 (Sol.)

$M = M_{vp} * M_{orth}$

$$\mathbf{M} = \begin{bmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x-1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y-1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$A' = M\,A$

$B' = M\,B$

Additional Reading

- Wireframe renderings
- Derive M_{orth}