

2D Transformations

2D Linear Transformations

- Each 2D linear map can be represented by a unique 2×2 matrix

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \cdot \begin{pmatrix} x \\ y \end{pmatrix}$$

- Concatenation of mappings corresponds to multiplication of matrices

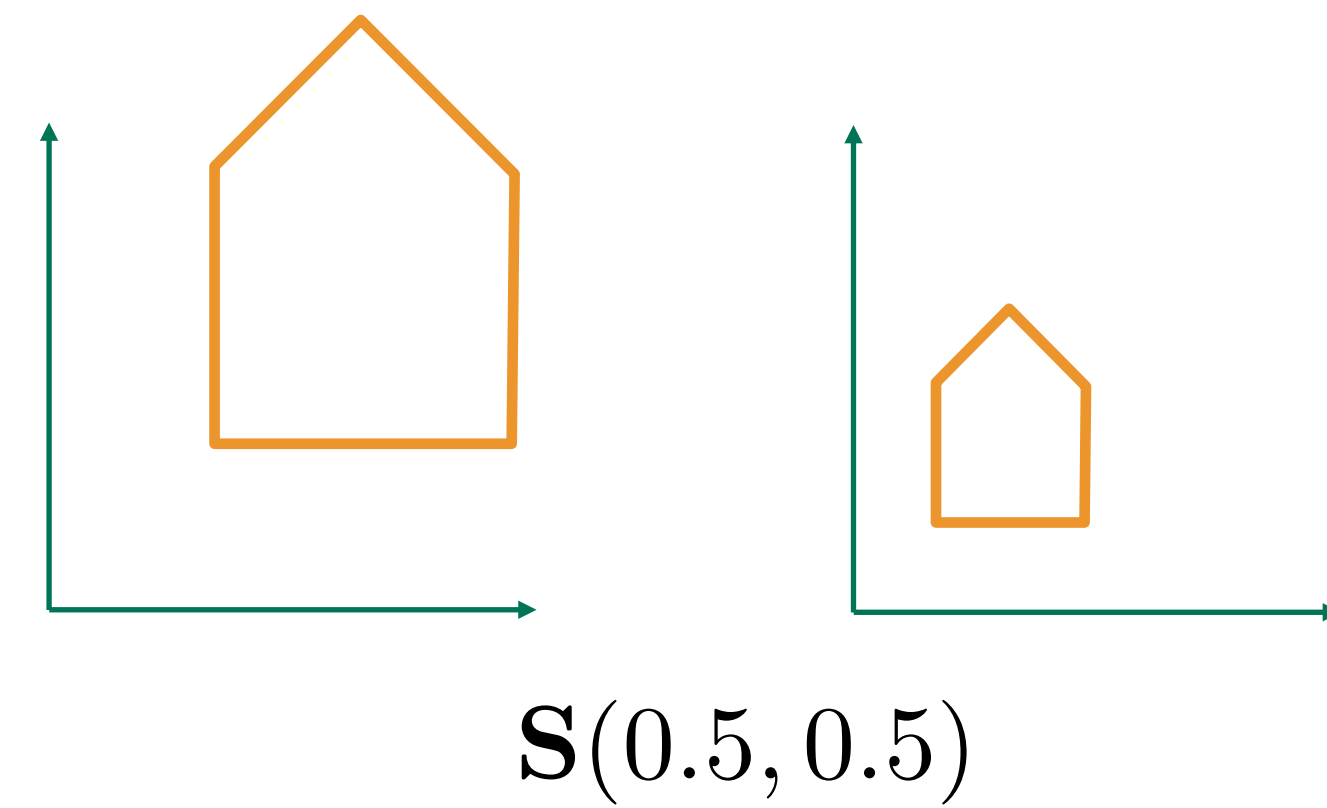
$$L_2(L_1(\mathbf{x})) = \mathbf{L}_2 \mathbf{L}_1 \mathbf{x}$$

$$\boxed{\mathbf{L}_2 * \mathbf{L}_1 * \mathbf{x};}$$

- Linear transformations are very common in computer graphics!

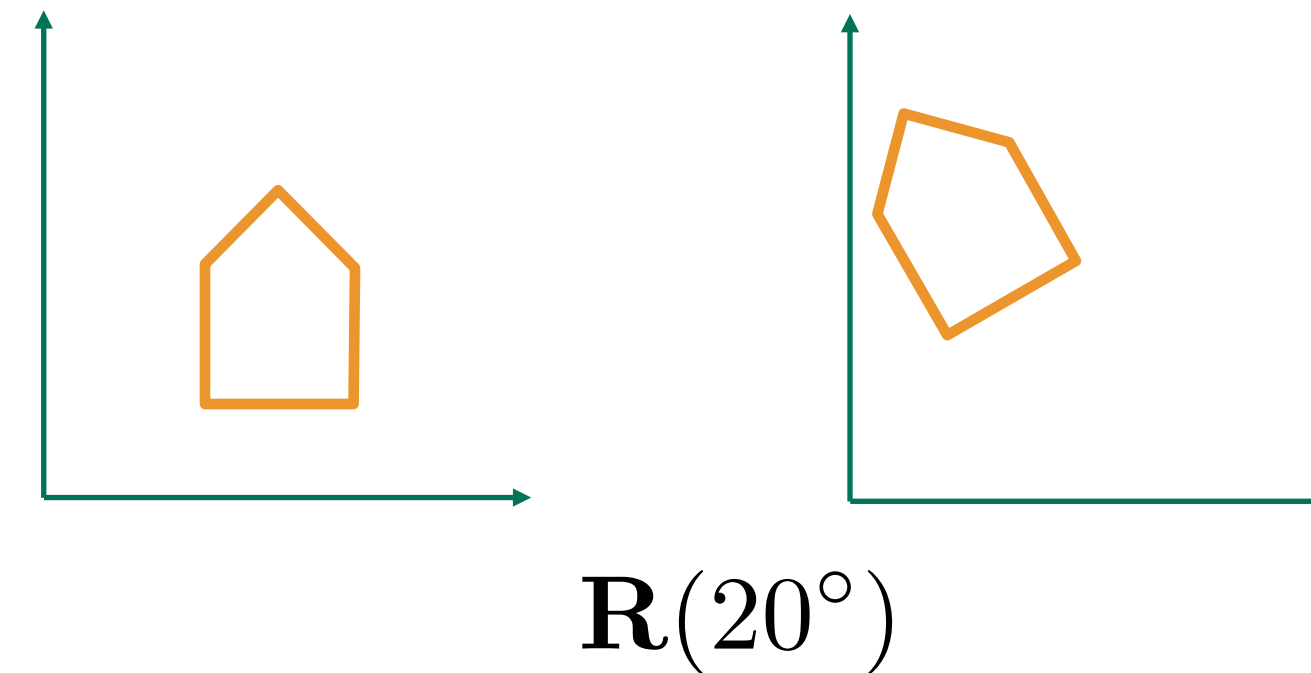
2D Scaling

- Scaling
$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \underbrace{\begin{pmatrix} s_x & 0 \\ 0 & s_y \end{pmatrix}}_{\mathbf{S}(s_x, s_y)} \cdot \begin{pmatrix} x \\ y \end{pmatrix}$$



2D Rotation

- Rotation $\begin{pmatrix} x' \\ y' \end{pmatrix} = \underbrace{\begin{pmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{pmatrix}}_{\mathbf{R}(\alpha)} \cdot \begin{pmatrix} x \\ y \end{pmatrix}$

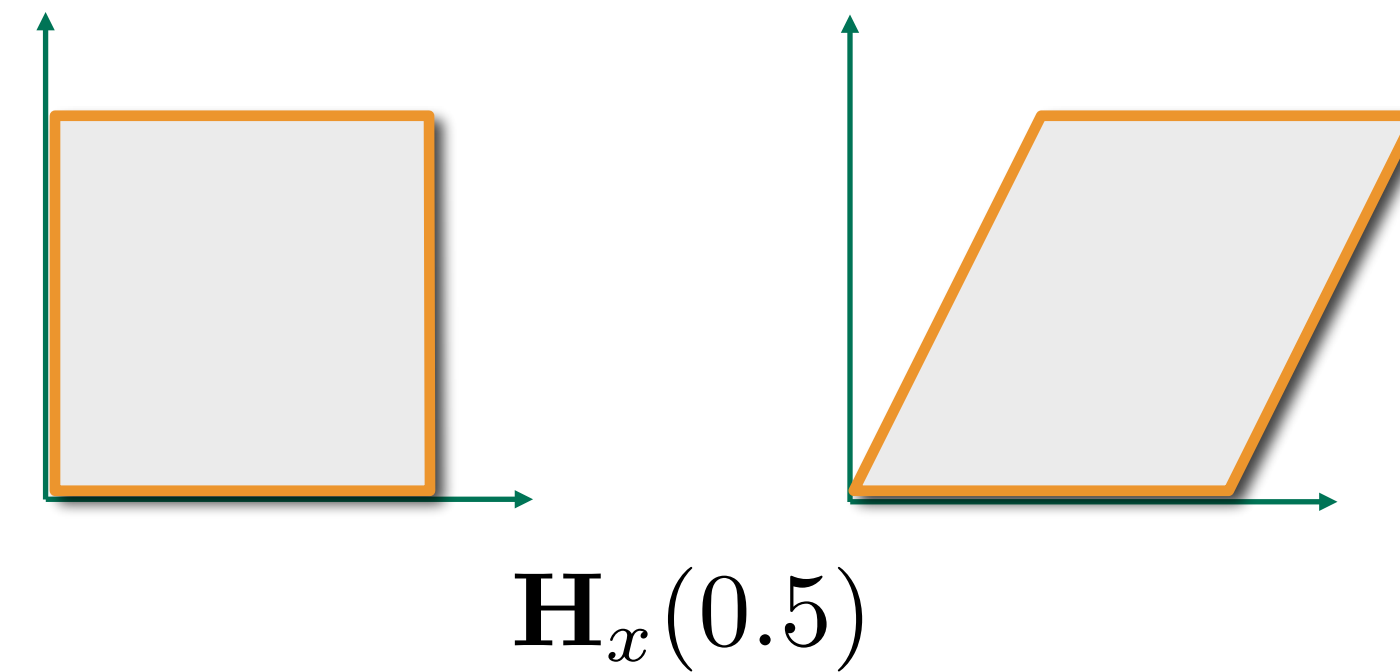


Special case: $\mathbf{R}(90) = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$

2D Shearing

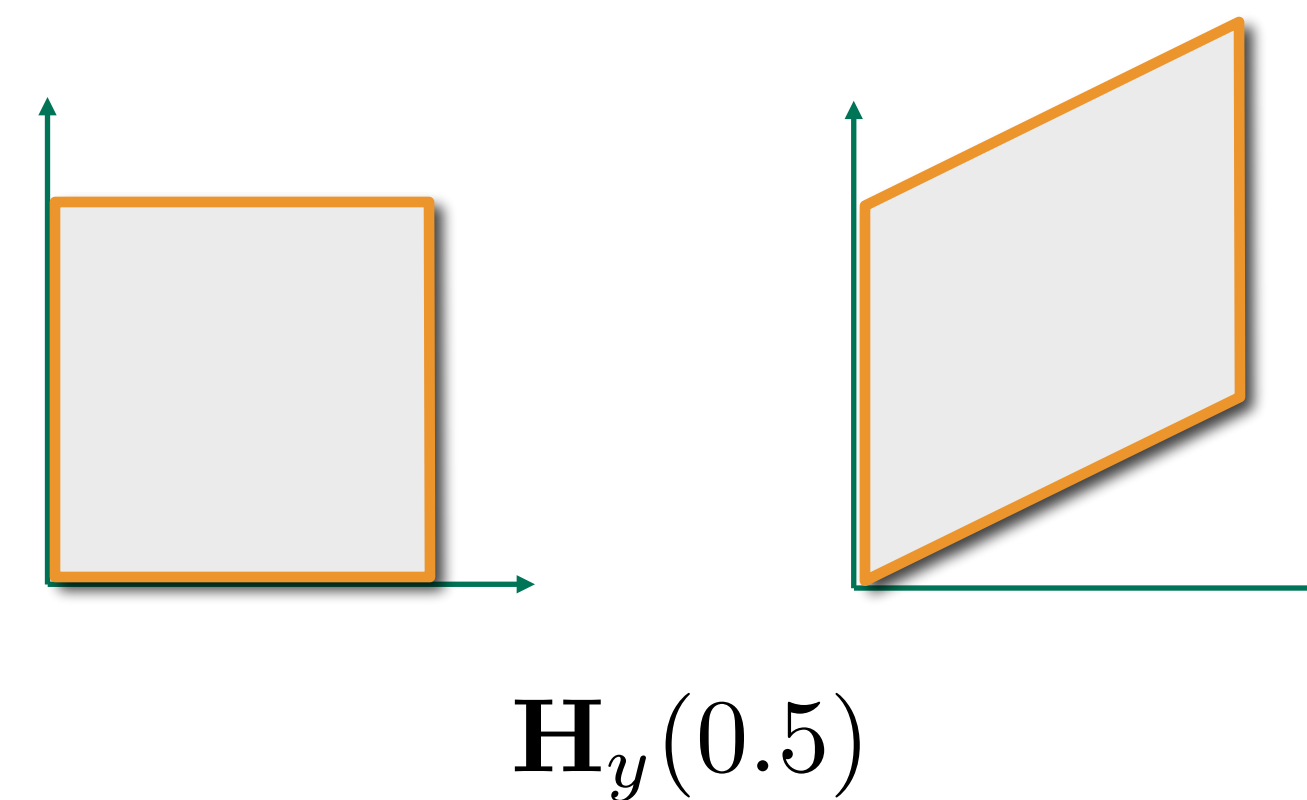
- Shear along x-axis

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \underbrace{\begin{pmatrix} 1 & a \\ 0 & 1 \end{pmatrix}}_{\mathbf{H}_x(a)} \cdot \begin{pmatrix} x \\ y \end{pmatrix}$$



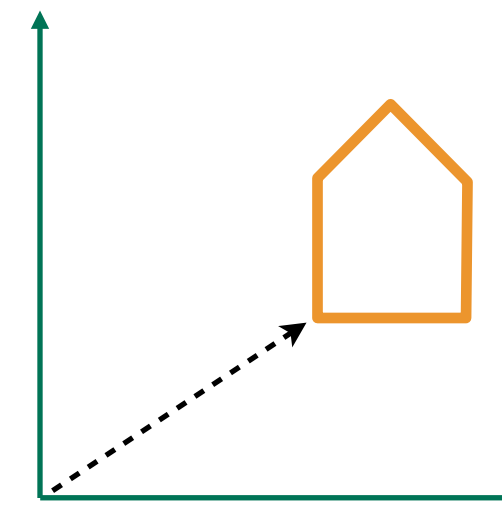
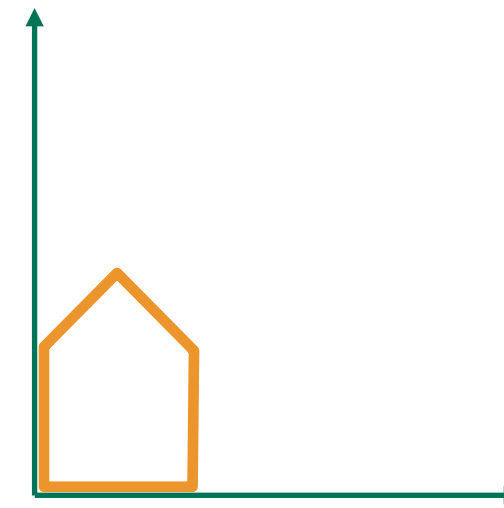
- Shear along y-axis

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \underbrace{\begin{pmatrix} 1 & 0 \\ b & 1 \end{pmatrix}}_{\mathbf{H}_y(b)} \cdot \begin{pmatrix} x \\ y \end{pmatrix}$$



2D Translation

- Translation $\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} t_x \\ t_y \end{pmatrix}$



- Matrix representation? $\begin{pmatrix} x' \\ y' \end{pmatrix} = \mathbf{T}(t_x, t_y) \cdot \begin{pmatrix} x \\ y \end{pmatrix}$

Affine Transformations

- Translation is not linear, but it is *affine*
 - Origin is no longer a fixed point
- Affine map = linear map + translation

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \cdot \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} t_x \\ t_y \end{pmatrix} = \mathbf{L}\mathbf{x} + \mathbf{t}$$

- Is there a matrix representation for affine transformations?
 - We would like to handle all transformations in a unified framework -> simpler to code and easier to optimize!

Homogenous Coordinates

- Add a third coordinate (*w-coordinate*)
- 2D point = $(x, y, 1)^T$
- 2D vector = $(x, y, 0)^T$

$$\begin{pmatrix} x' \\ y' \\ w' \end{pmatrix} = \begin{pmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = \begin{pmatrix} x + t_x \\ y + t_y \\ 1 \end{pmatrix}$$

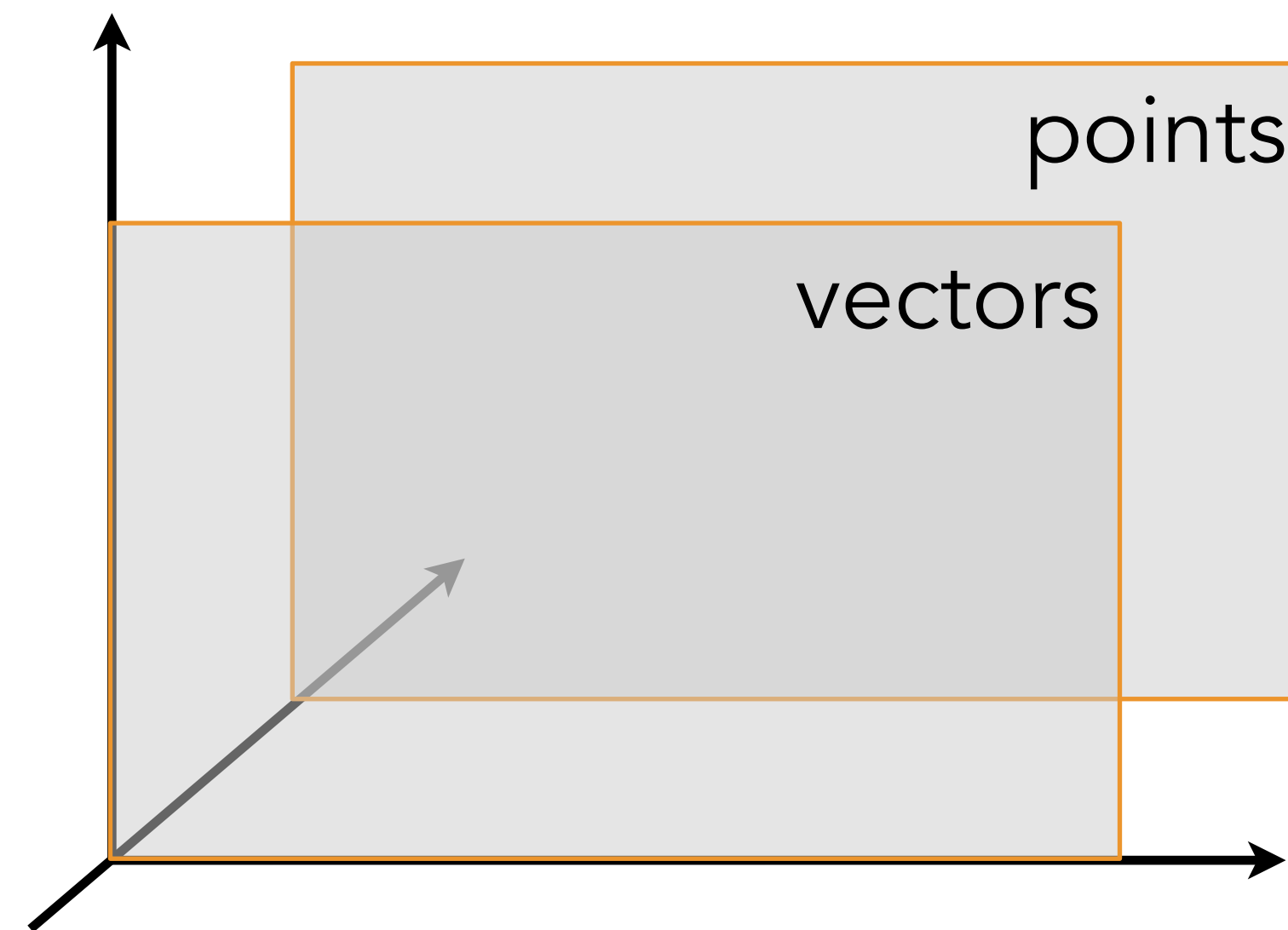
- Matrix representation of translations

Homogenous Coordinates

- Valid operation if the resulting w-coordinate is 1 or 0
 - $\text{vector} + \text{vector} = \text{vector}$
 - $\text{point} - \text{point} = \text{vector}$
 - $\text{point} + \text{vector} = \text{point}$
 - $\text{point} + \text{point} = ???$

Homogenous Coordinates

- Geometric interpretation: 2 hyperplanes in \mathbf{R}^3



Affine Transformations

- Affine map = linear map + translation

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \cdot \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} t_x \\ t_y \end{pmatrix}$$

- Using homogenous coordinates:

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} a & b & t_x \\ c & d & t_y \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

2D Transformations

- Scale

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

- Rotation

$$\mathbf{R}(\alpha) = \begin{pmatrix} \cos \alpha & -\sin \alpha & 0 \\ \sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- Translation

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

Concatenation of Transformations

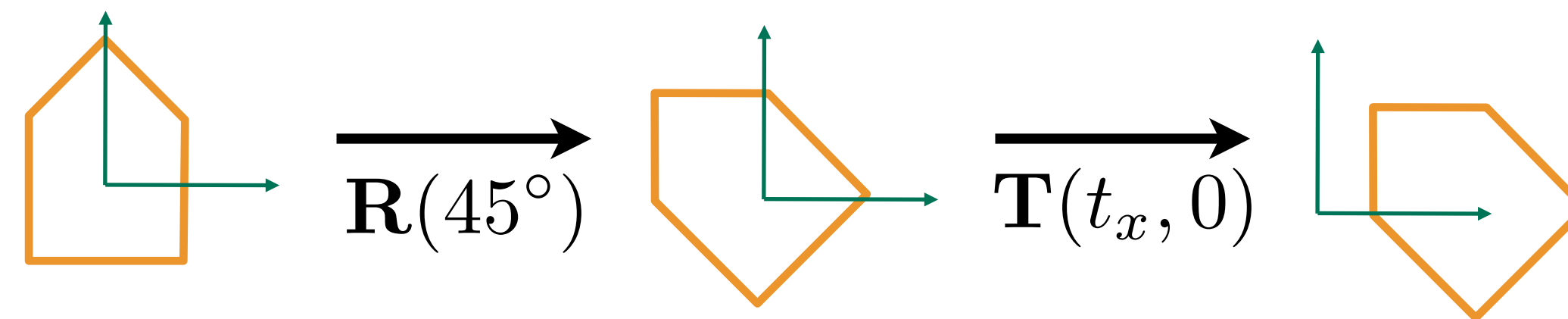
- Sequence of affine maps $\mathbf{A}_1, \mathbf{A}_2, \mathbf{A}_3, \dots$
- Concatenation by matrix multiplication

$$A_n(\dots A_2(A_1(\mathbf{x}))) = \mathbf{A}_n \cdots \mathbf{A}_2 \cdot \mathbf{A}_1 \cdot \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

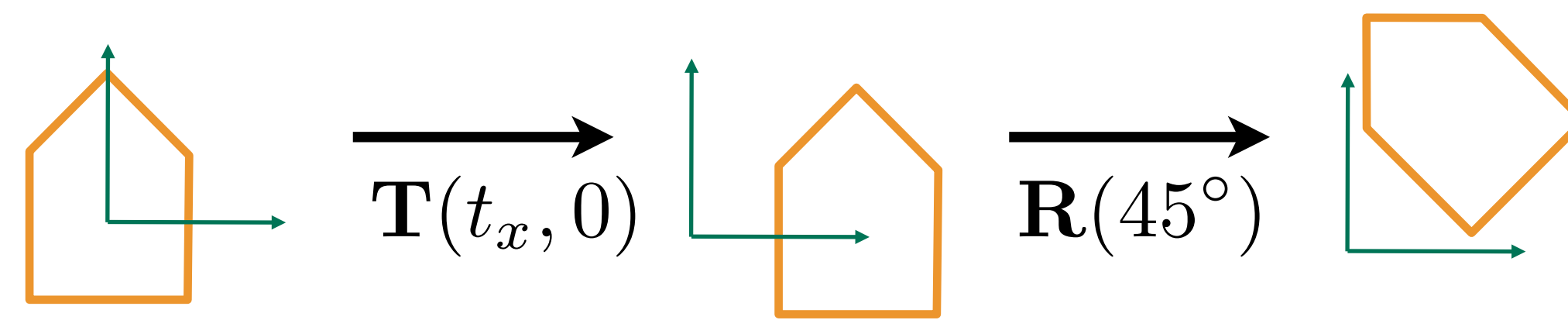
- Very important for performance!
- Matrix multiplication not commutative, ordering is important!

Rotation and Translation

- Matrix multiplication is not commutative!
- First rotation, then translation

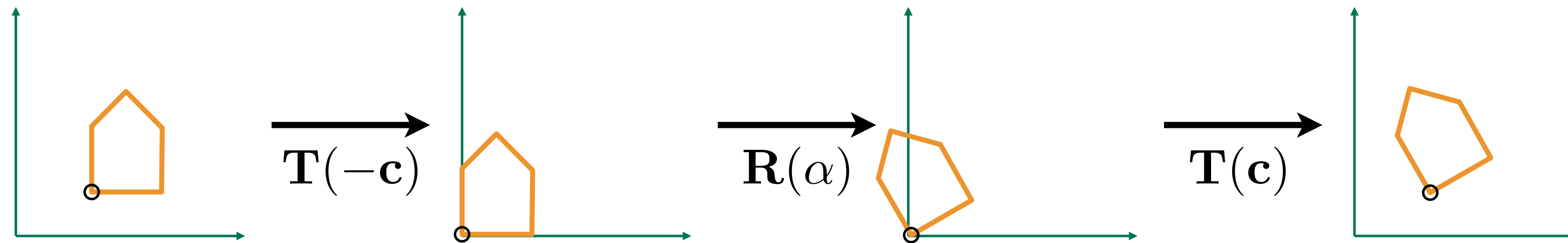


- First translation, then rotation



2D Rotation

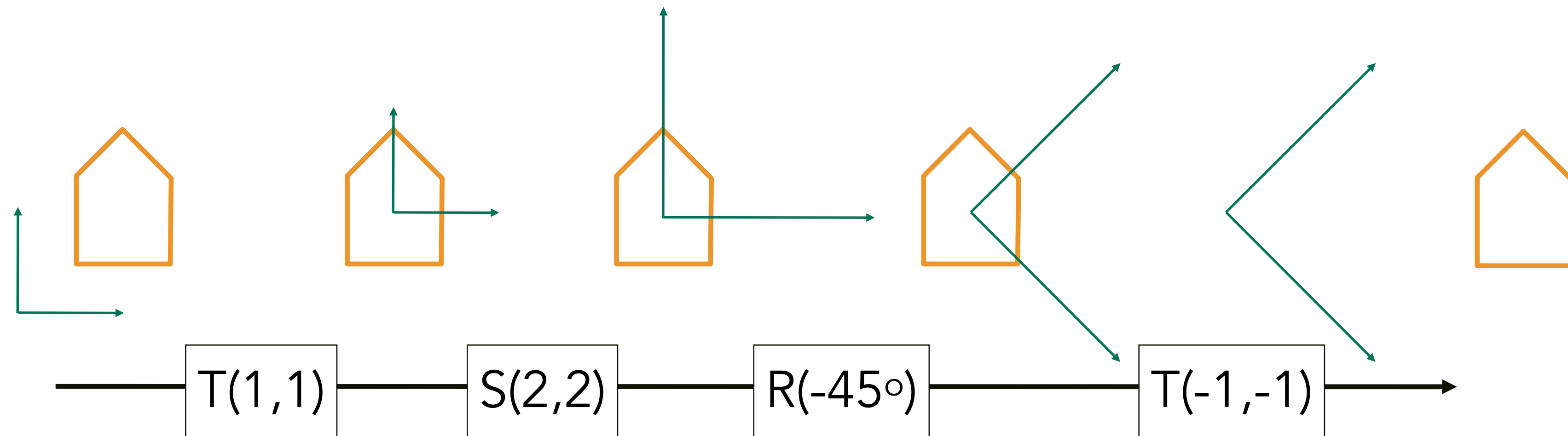
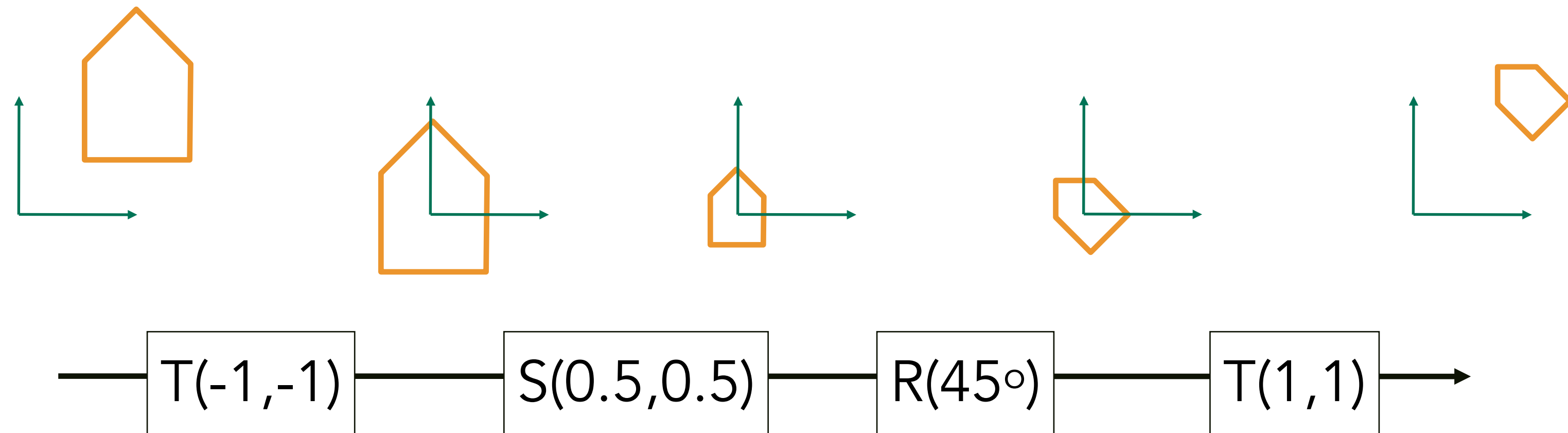
- How to rotate around a given point \mathbf{c} ?
 1. Translate \mathbf{c} to origin
 2. Rotate
 3. Translate back



- Matrix representation?

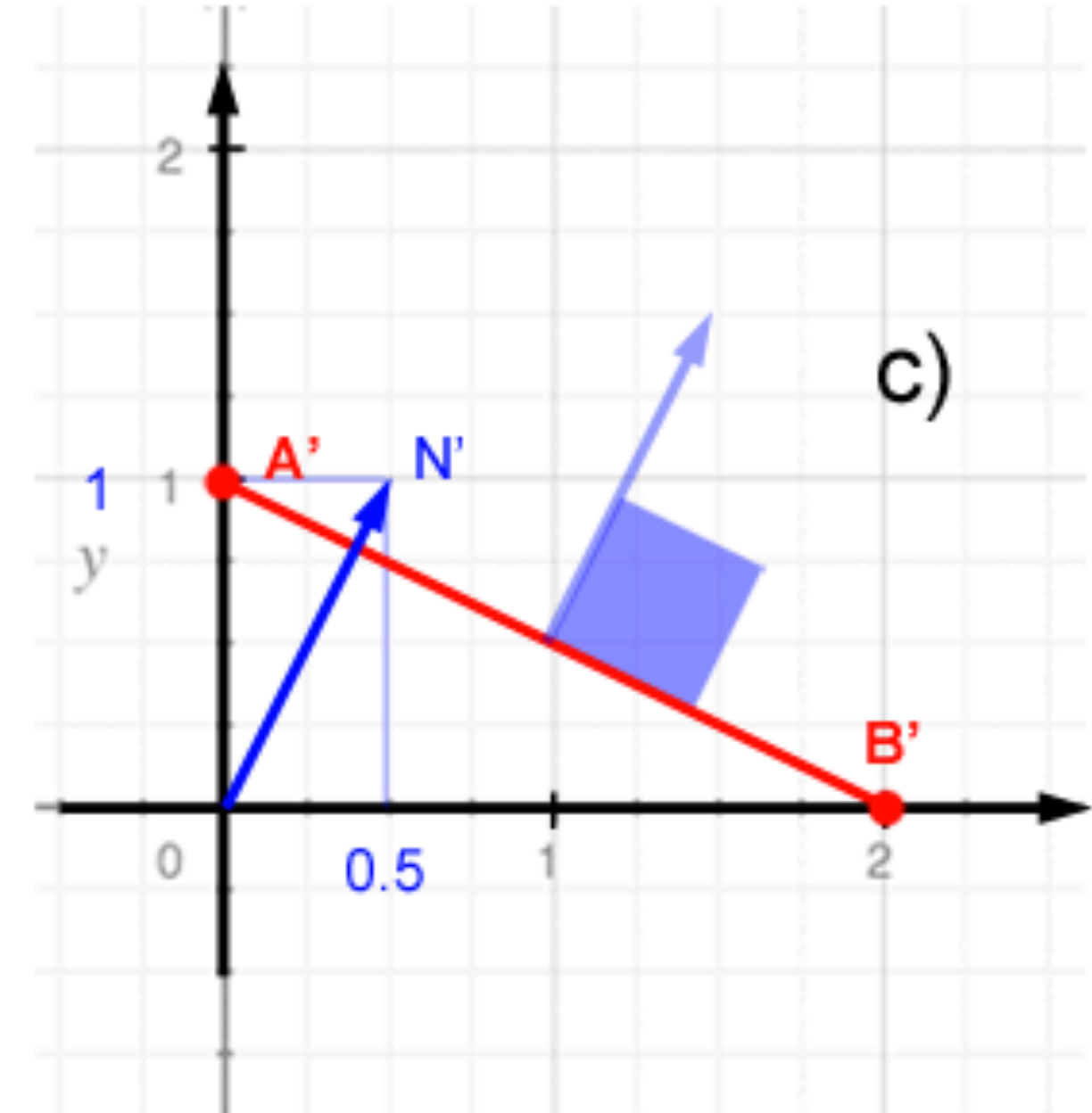
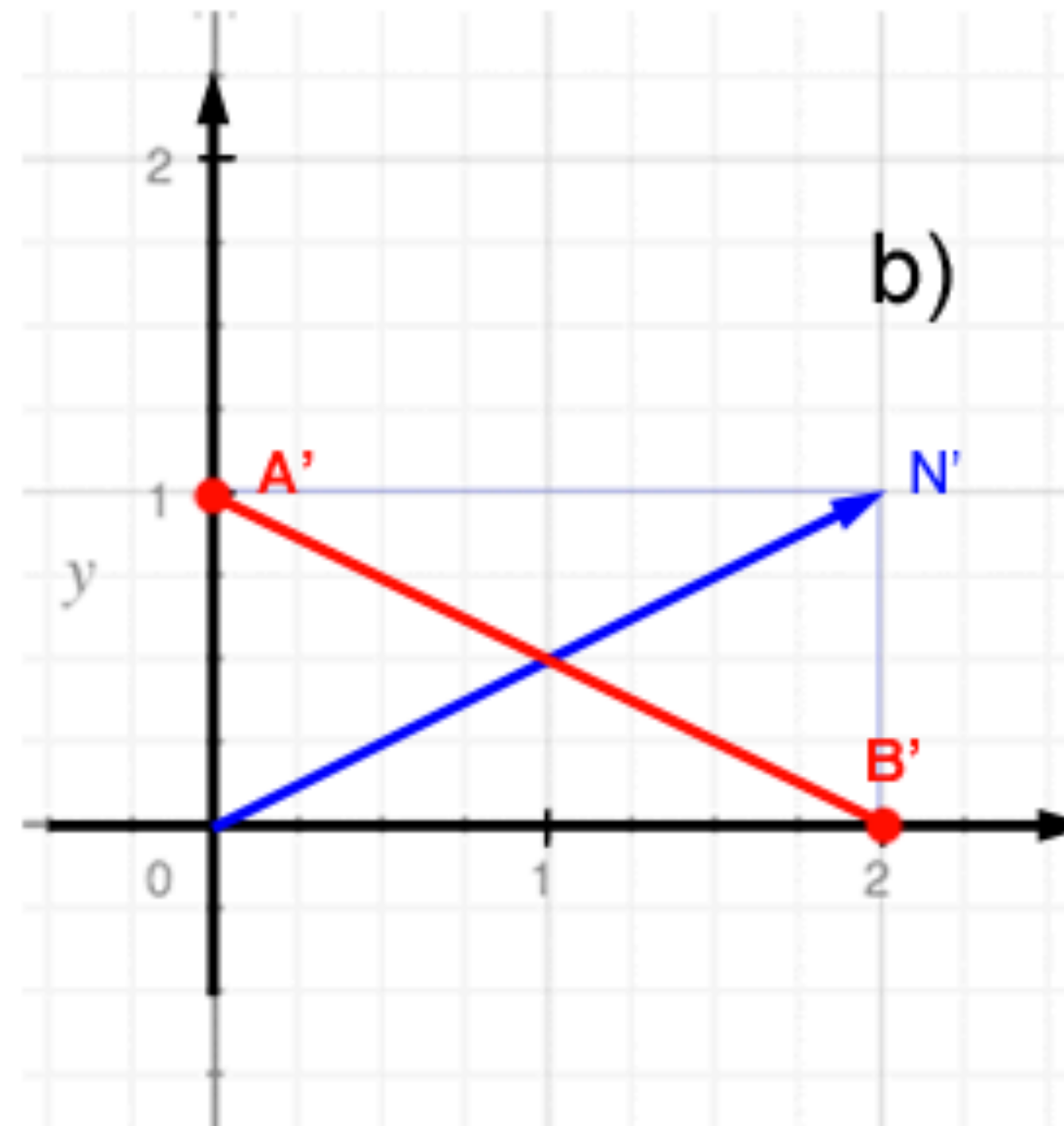
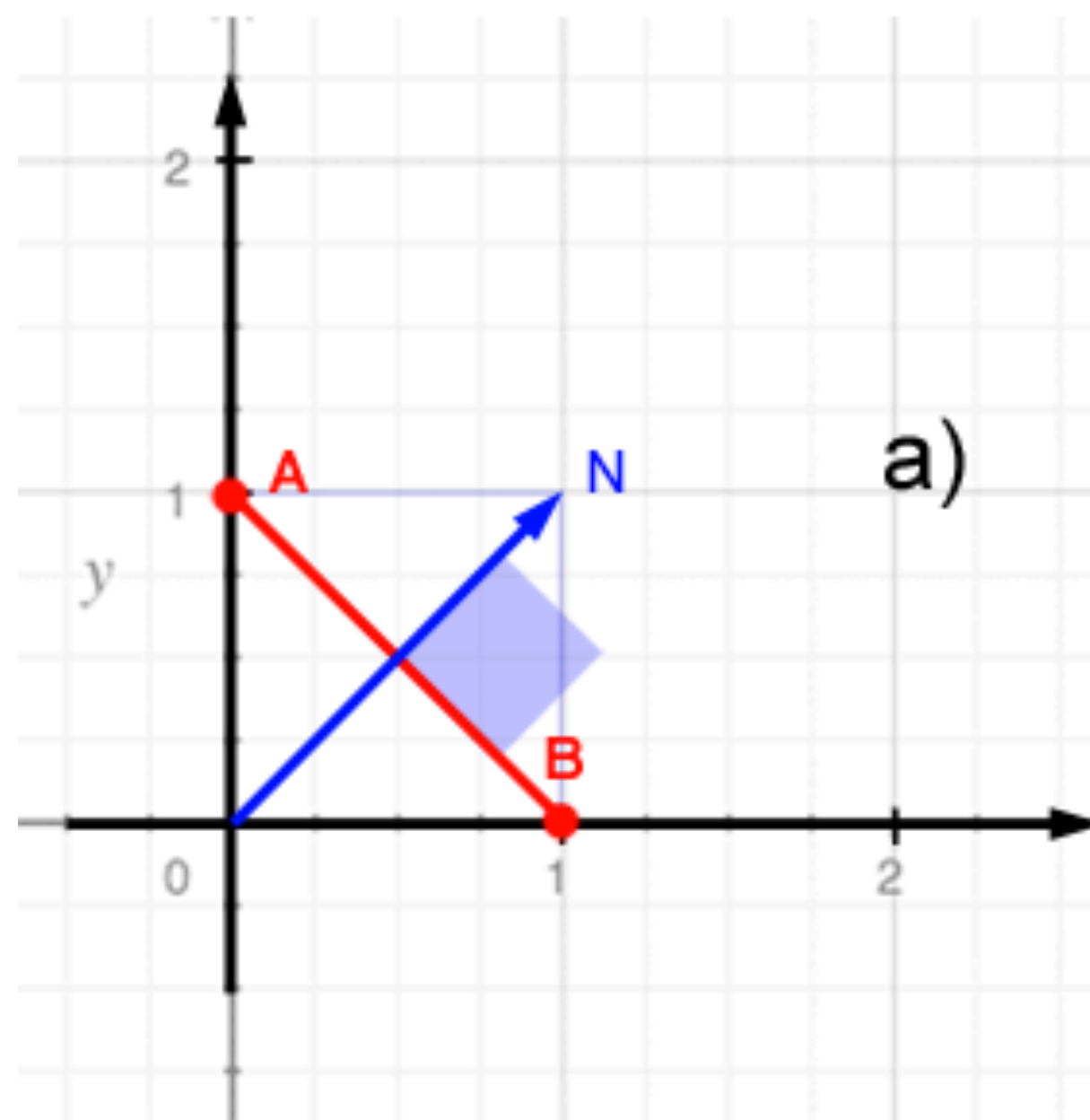
$$\mathbf{T}(\mathbf{c}) \cdot \mathbf{R}(\alpha) \cdot \mathbf{T}(-\mathbf{c})$$

Transform Object or Camera?



A note on transforming normals

- If you transform a point \mathbf{v} with a matrix \mathbf{M} : $\mathbf{v}' = \mathbf{M}\mathbf{v}$...
- the transformed normal \mathbf{n}' at the point \mathbf{v} is $\mathbf{n}' = \mathbf{M}^{-T} \mathbf{n}$



References

Fundamentals of Computer Graphics, Fourth Edition
4th Edition **by Steve Marschner, Peter Shirley**

Chapter 6