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Lecture 15

2D Sprite Graphics

Graphics Lectures

- Drawing Images
  - SpriteBatch interface
  - Coordinates and Transforms
- Drawing Perspective
  - Camera
  - Projections
- Drawing Primitives
  - Color and Textures
  - Polygons

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Graphics Lectures

- Drawing Images
  - SpriteBatch interface
  - Coordinates and Transforms

bare minimum
to draw graphics

- Drawing Perspective
  - Camera
  - Projections

side-scroller vs.
top down

- Drawing Primitives
  - Color and Textures
  - Polygons

necessary for
lighting & shadows

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Graphics Lectures

- Drawing Images
  - SpriteBatch interface
  - Coordinates and Transforms
- Drawing Perspective
  - Camera
  - Projections
- Drawing Primitives
  - Color and Textures
  - Polygons

No **Animation**:
For AI Lectures

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Graphics Lectures

- **Drawing Images**
  - SpriteBatch interface
  - Coordinates and Transforms

bare minimum
to draw graphics

- Drawing Perspective
  - Camera
  - Projections

side-scroller vs.
top down

- Drawing Primitives
  - Color and Textures
  - Polygons

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Take Away for Today

- **Coordinate Spaces** and drawing
  - What is screen space? Object space?
  - How do we use the two to draw objects?
  - Do we need any other spaces as well?
- **Drawing Transforms**
  - What is a drawing transform?
  - Describe the classic types of transforms.
  - List how to use transforms in a game.

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The `SpriteBatch` Interface

- In this class we restrict you to 2D graphics
  - 3D graphics are much more complicated
  - Covered in much more detail in other classes
    - Art 1701: Artist tools for 3D Models
    - CS 4620: Programming with 3D models
- In LibGDX, use the class `SpriteBatch`
  - **Sprite**: Pre-rendered 2D (or even 3D) image
  - All you do is *composite* the sprites together

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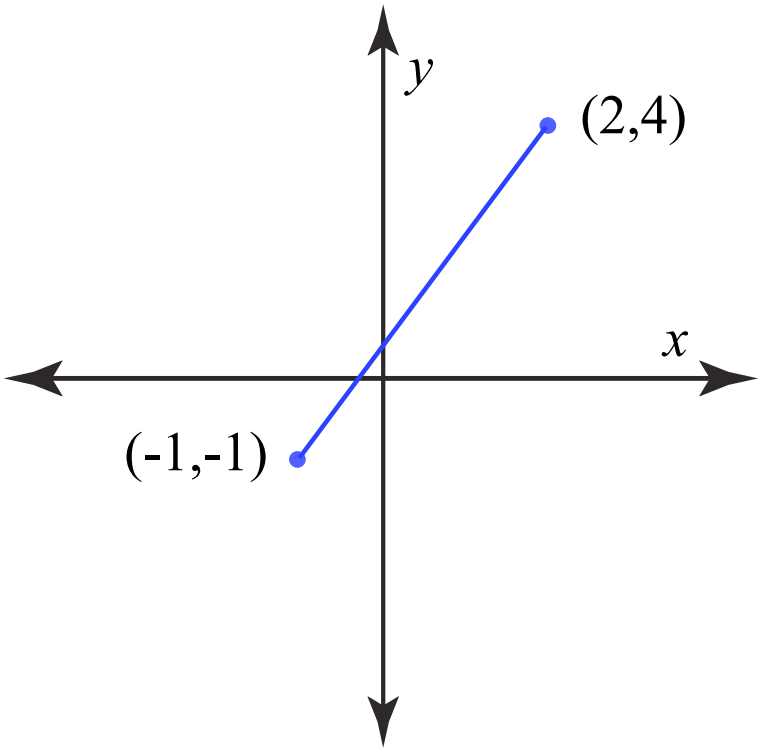
Drawing in 2 Dimensions

- Use **coordinate systems**
  - Each pixel has a coordinate
  - Draw something at a pixel by
    - Specifying what to draw
    - Specifying where to draw
- Do we draw each pixel?
  - Use a drawing API
  - Given an image; does work
  - What LibGDX gives us



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Sprite Coordinate Systems

- **Screen coordinates**: where to paint the image
  - Think screen pixels as a coordinate system
  - Very important for object *transformations*
    - **Example**: scale, rotate, translate
  - In 2D, LibGDX origin is **bottom left** of screen
- **Object coordinate**: location of pixels in object
  - Think of sprite as an image file (it often is)
  - Coordinates are location of pixels in this file
  - Unchanged when object moves about screen

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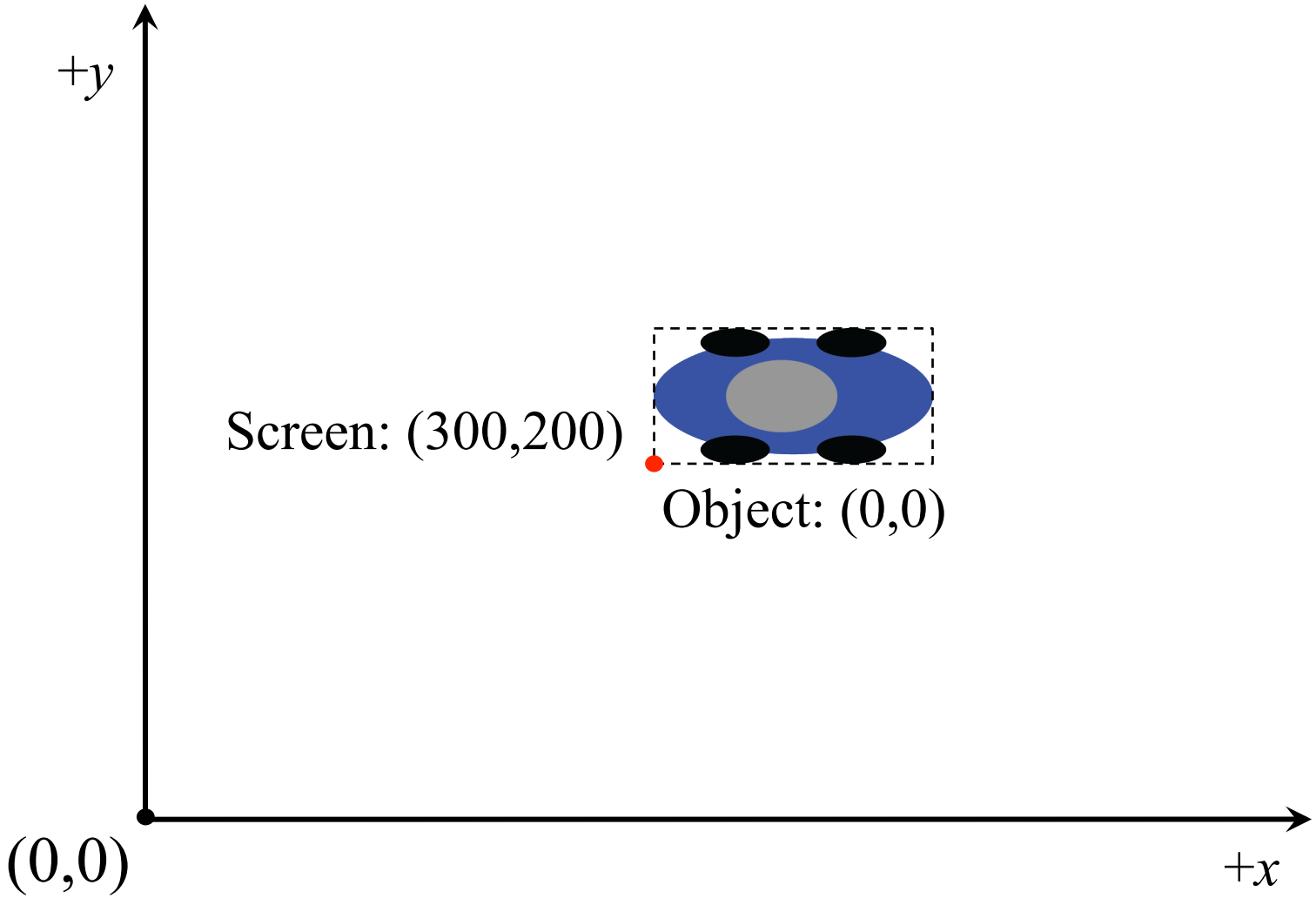
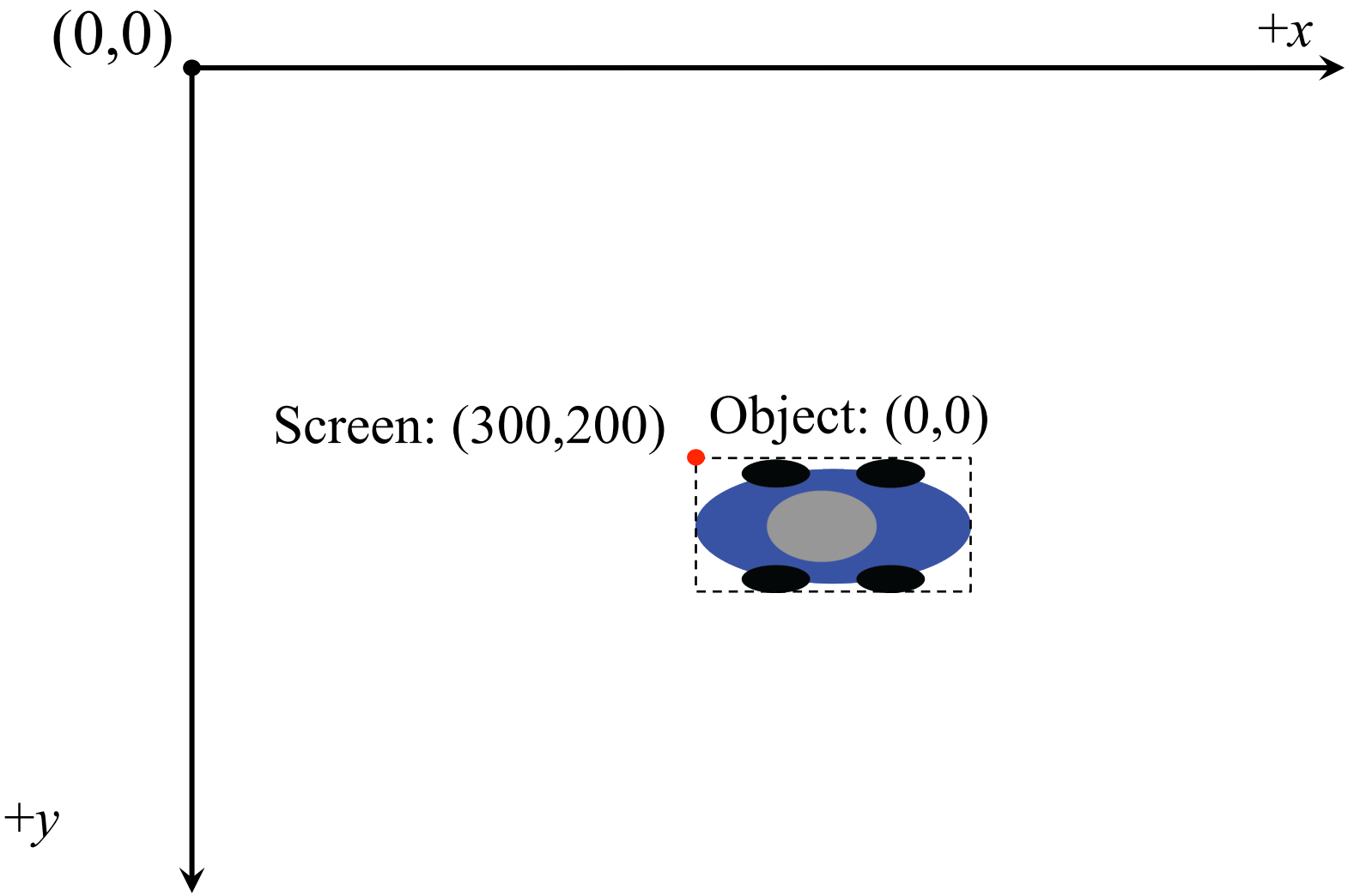
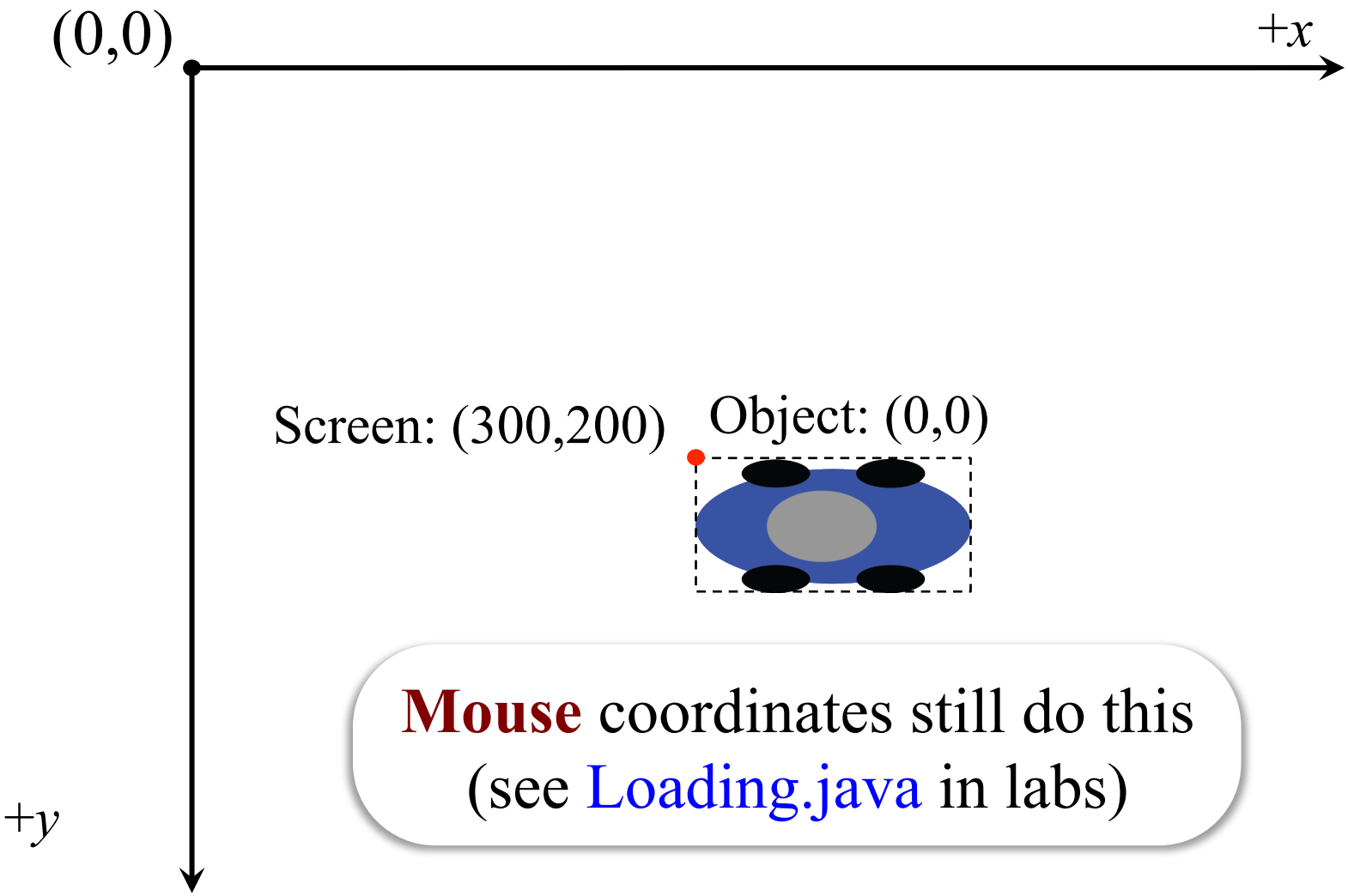
Sprite Coordinate Systems



Historical Coordinate Systems



Historical Coordinate Systems



Mouse coordinates still do this
(see Loading.java in labs)

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Drawing Sprites

- **Basic instructions**:
  - Set origin for the image in object coordinates
  - Give the `SpriteBatch` a point to draw at
  - Screen places origin of image at that point
- What about the other pixels?
  - Depends on transformations (rotated? scaled?)
  - But these (almost) never affect the origin
- Sometimes we can **reset** the object origin

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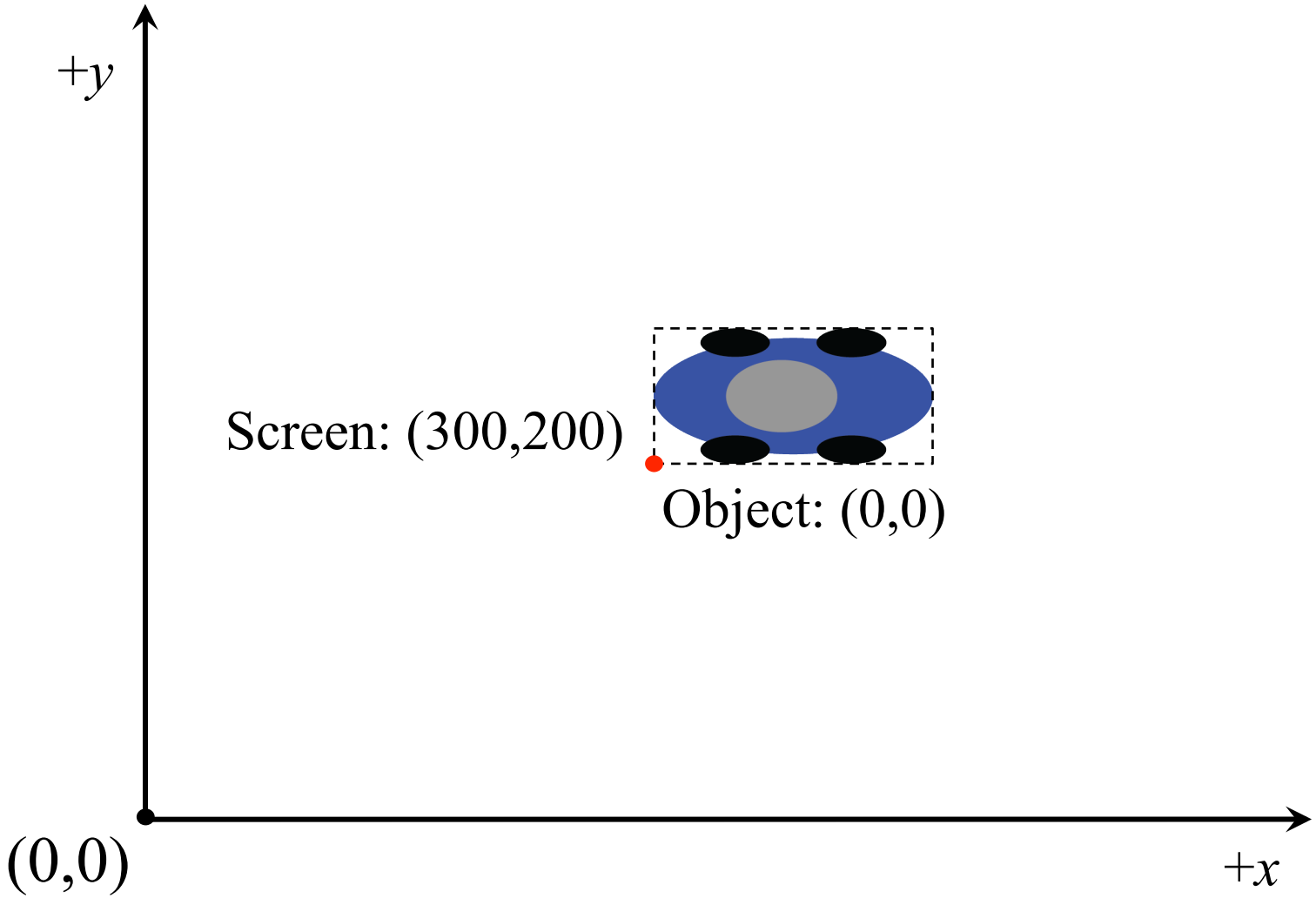
Sprite Coordinate Systems



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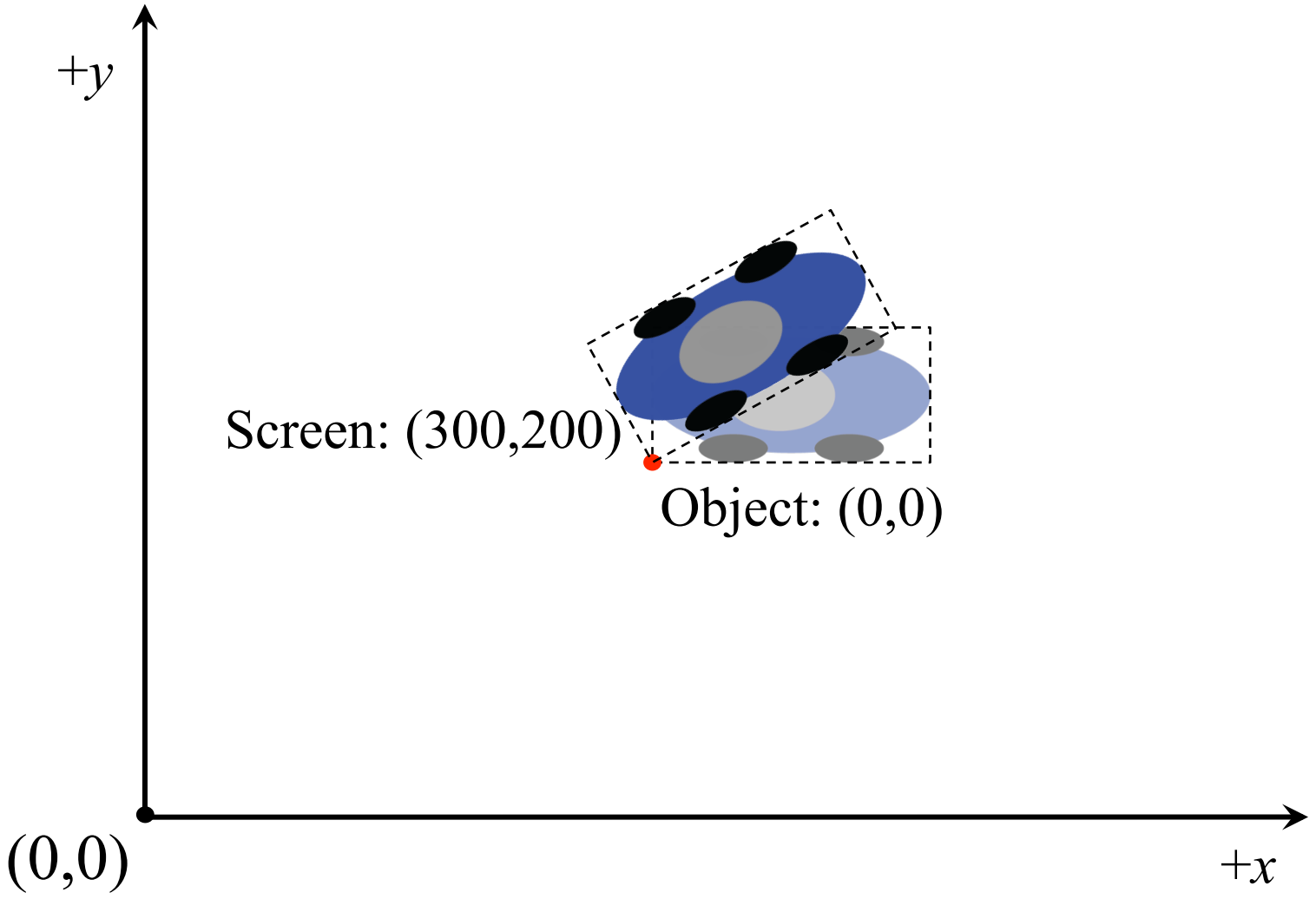
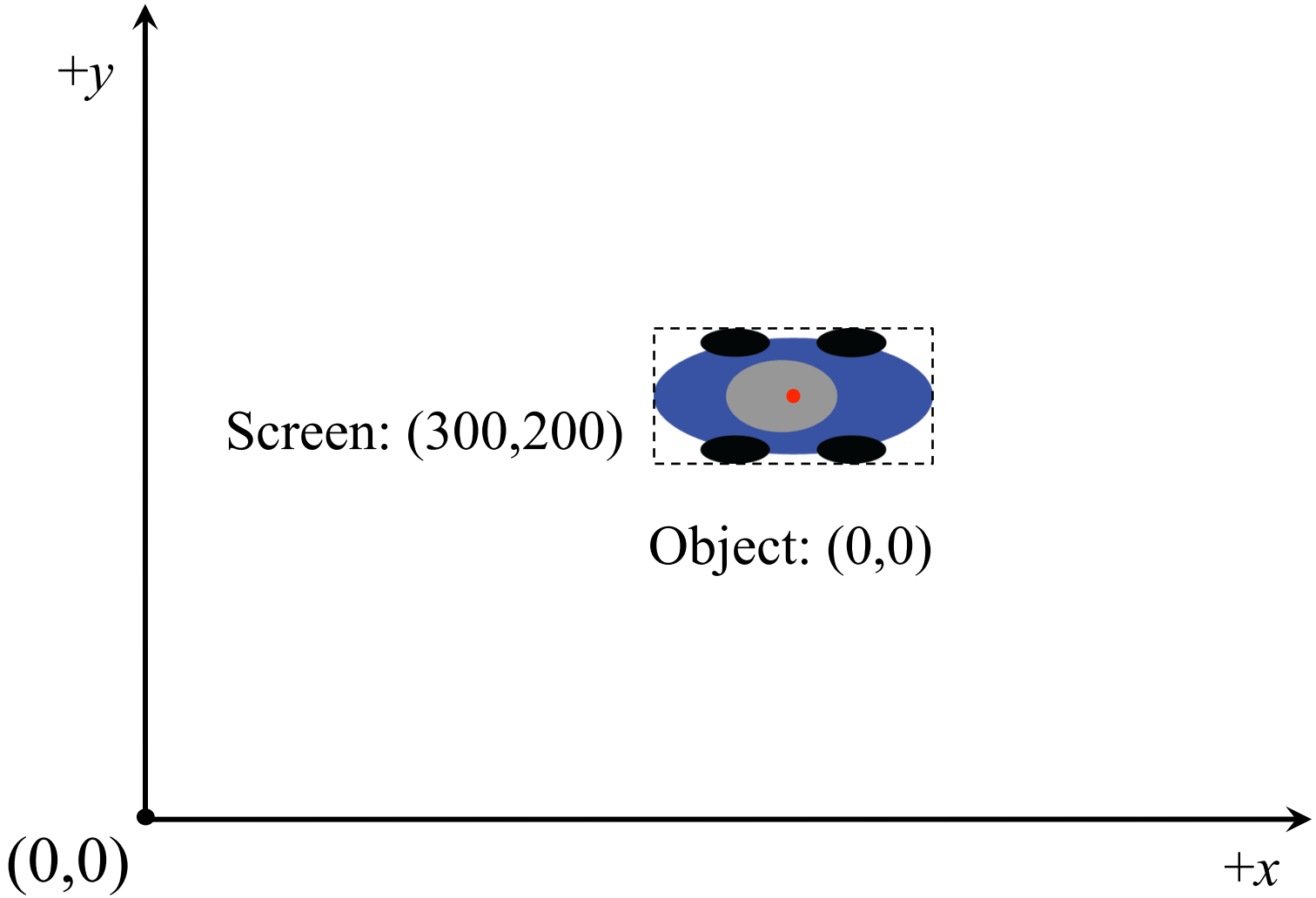
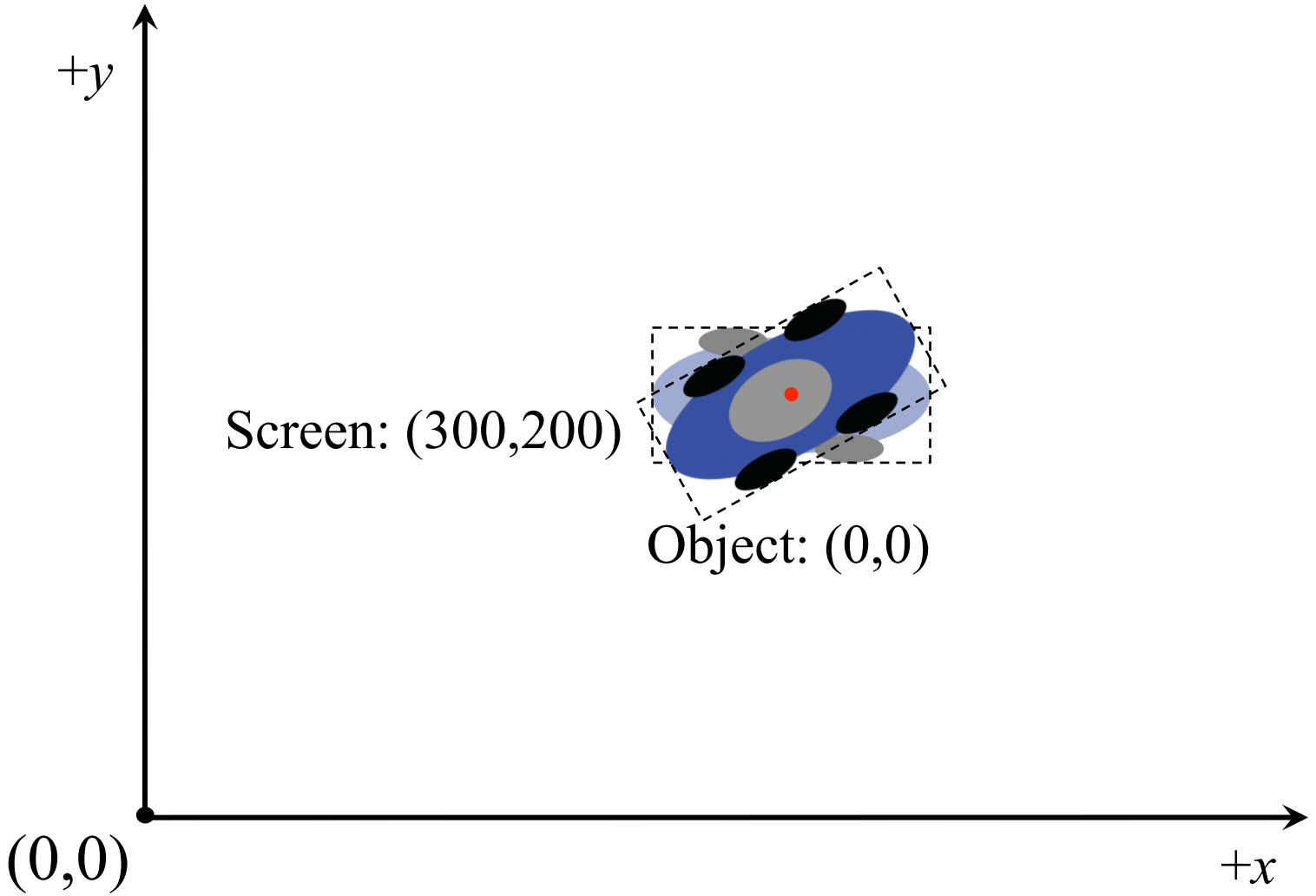
Sprite Coordinate Systems



Sprite Coordinate Systems



Sprite Coordinate Systems



Drawing with SpriteBatch

```
public void draw(float dt) {
    ...
    spriteBatch.begin();
    spriteBatch.draw(image0);
    spriteBatch.draw(image1, pos.x, pos.y);
    ...
    spriteBatch.end();
    ...
}
```

screen coordinates

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2D Transforms

- A function $T : \mathbb{R}^2 \rightarrow \mathbb{R}^2$
  - "Moves" one set of points to another set of points
  - Transforms one "coordinate system" to another
  - The new coordinate system is the distortion
- **Idea**: Draw on paper and then "distort" it
  - **Examples**: Stretching, rotating, reflecting
  - Determines placement of "other" pixels
  - Also allows us to get multiple images for free

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The "Drawing Transform"

- T : object coords → screen coords
  - Assume pixel (a,b) in art file is blue
  - Then screen pixel $T(a,b)$ is blue
  - We call T the **object map**
- By default, object space = screen space
  - Color of image at (a,b) = color of screen at (a,b)
  - By drawing an image, you are *transforming* it
- **S** an image; transformed image is $T(\mathbf{S})$

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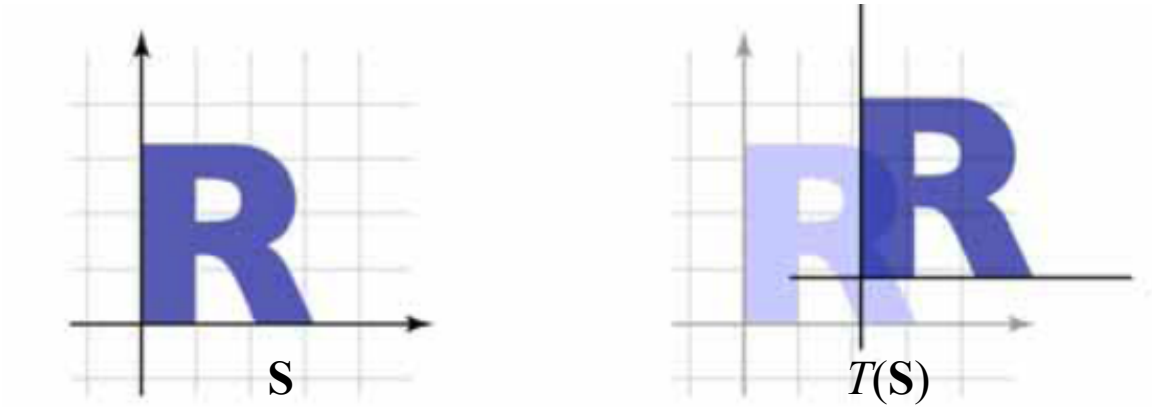
Example: Translation

- Simplest transformation: $T(\mathbf{v}) = \mathbf{v} + \mathbf{u}$
  - Shifts object in direction **u**
  - Distance shifted is magnitude of **u**
- Used to place objects on screen
  - By default, object origin is screen origin
  - $T(\mathbf{v}) = \mathbf{v} + \mathbf{u}$ places object origin at **u**



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Composing Transforms

- **Example**: $T : \mathbb{R}^2 \rightarrow \mathbb{R}^2$, $S : \mathbb{R}^2 \rightarrow \mathbb{R}^2$
  - Assume pixel (a,b) in art file is blue
  - Transform T makes pixel $T(a,b)$ blue
  - Transform $S \circ T$ makes pixel $S(T(a,b))$ blue
- **Strategy**: use transforms as building blocks
  - Think about what you want to do visually
  - Break it into a sequence of transforms
  - Compose the transforms together

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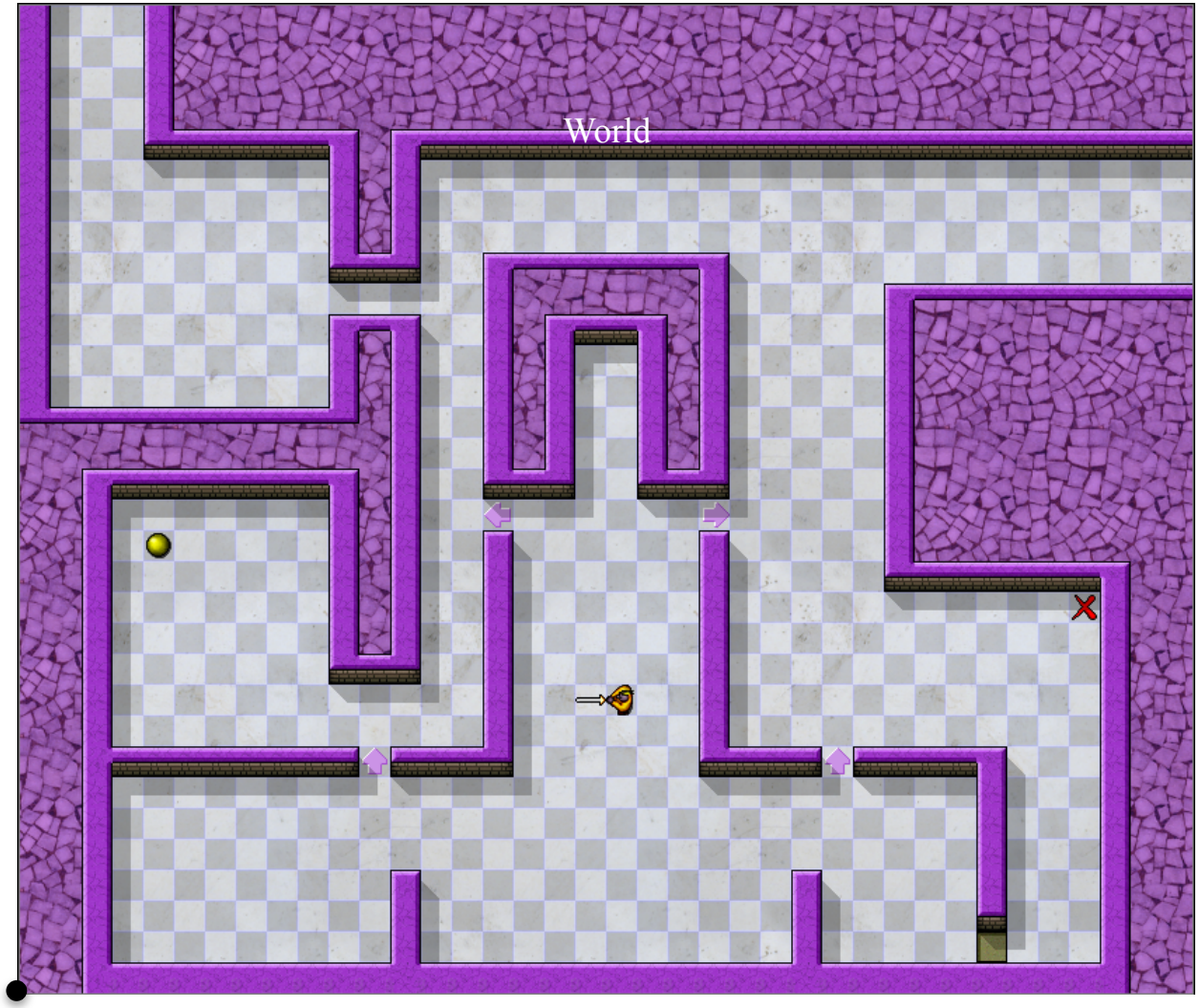
Application: Scrolling

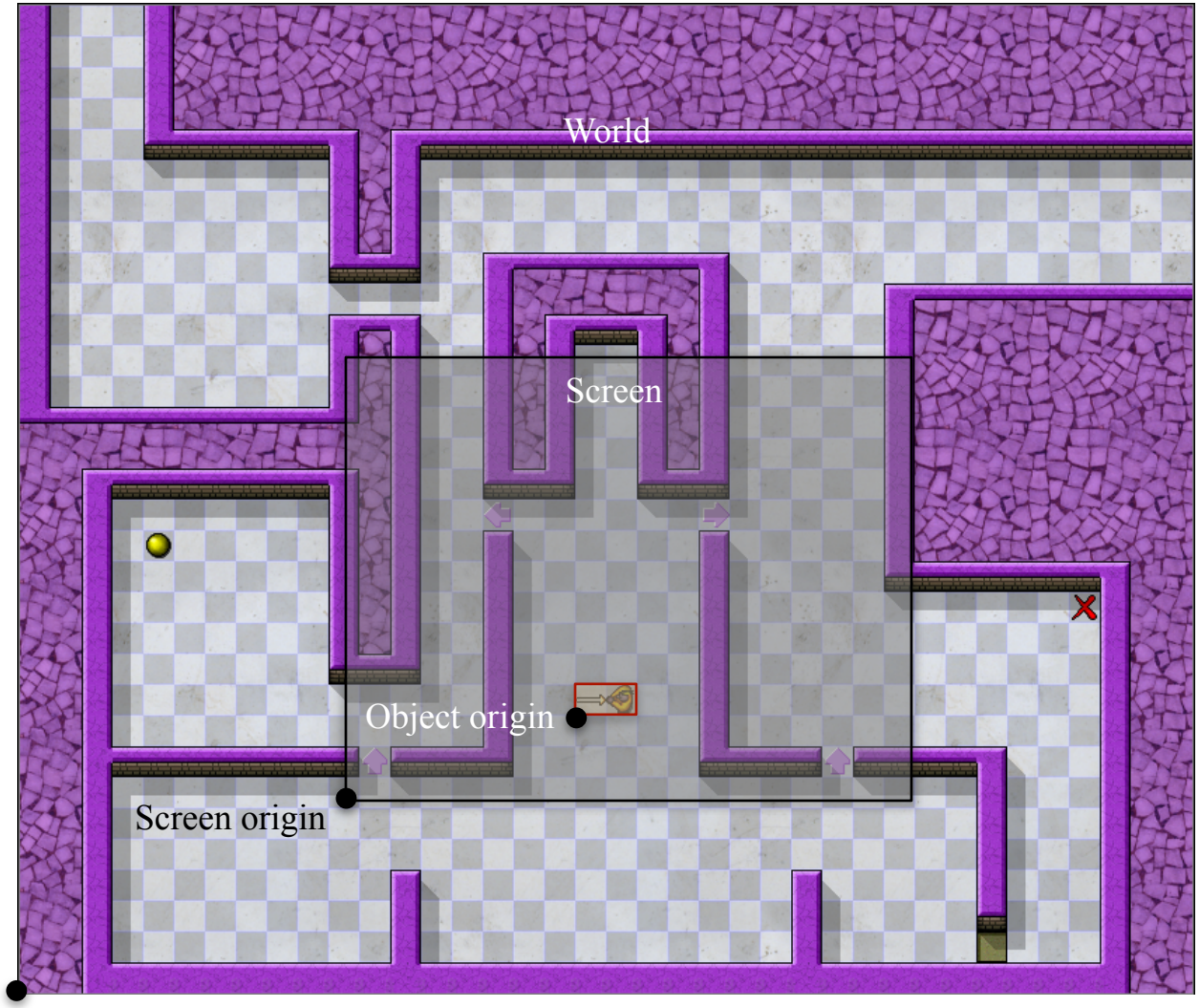


World origin

Application: Scrolling

World origin

Application: Scrolling



World origin

Scrolling: Two Translations

- Place object in the World at point $\mathbf{p} = (x,y)$
  - Basic drawing transform is $T(\mathbf{v}) = \mathbf{v}+\mathbf{p}$
- Suppose Screen origin is at $\mathbf{q} = (x',y')$
  - Then object is on the Screen at point $\mathbf{p}-\mathbf{q}$
  - $S(\mathbf{v}) = \mathbf{v}-\mathbf{q}$ transforms World coords to Screen
  - $S \circ T(\mathbf{v})$ transforms the Object to the Screen
- This separation makes scrolling easy
  - To move the object, change T but leave S same
  - To scroll the screen, change S but leave T same

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Scrolling: Practical Concerns

- Many objects will exists outside screen
  - Can draw if want; graphics card will drop them
  - It is expensive to keep track of them all
  - But is also unrealistic to always ignore them
- In graphics, drawing transform = matrix
  - Hence composition = matrix multiplication
  - Details beyond the scope of this course
  - LibGDX handles all of this for you (sort of)

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Using Transforms in LibGDX

- LibGDX has methods for creating transforms
  - Two types depending on application
  - `Affine2` for transforming 2D sprites
  - `Matrix4` for transforming 3D object
    - But also for transforming **fonts**
- Parameters fill in details about transform
  - **Example**: Position (x,y) if a translation
  - The most math you will ever need for this

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Transforms in SpriteBatch

Affine2

- Pass it to a draw command
  - Applies only to that image
  - Adds to CPU power
- Handles everything
  - Location is in transform
  - Transform to object position
- `sb.draw(image,wd,ht,affine);`

Matrix4

- Pass to setTransformMatrix
  - Applies to all images!
  - Handled by the GPU but…
  - Change causes GPU stall
- Only use this if you must
  - e.g. Transforming fonts
  - See GameCanvas in Lab1

Transforms in SpriteBatch

Affine2

- Pass it to a draw command
  - Applies only to that image
  - Adds to CPU power
- Handles everything
  - Location is in transform
  - Transform to object position
- `sb.draw(image,wd,ht,affine);`

Only supports a **TextureRegion**??

Matrix4

- Pass to setTransformMatrix
  - Applies to all images!
  - Handled by the GPU but…
  - Change causes GPU stall
- Only use this if you must
  - e.g. Transforming fonts
  - See GameCanvas in Lab1

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Positioning in LibGDX

```
public void draw(float dt) {

    Vector2 pos = object.getPosition();




    spriteBatch.begin();
        spriteBatch.draw(image,pos.x,pos.y);
    spriteBatch.end();
}
```


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Positioning in LibGDX

```
public void draw(float dt) {
    Affine2 oTran = new Affine2();
    oTran.setToTranslation(object.getPosition());
```

Translate origin to position in world.

```
    spriteBatch.begin();
        spriteBatch.draw(image,width,height,oTran);
    spriteBatch.end();
}
```

why did they do this???

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Positioning in LibGDX

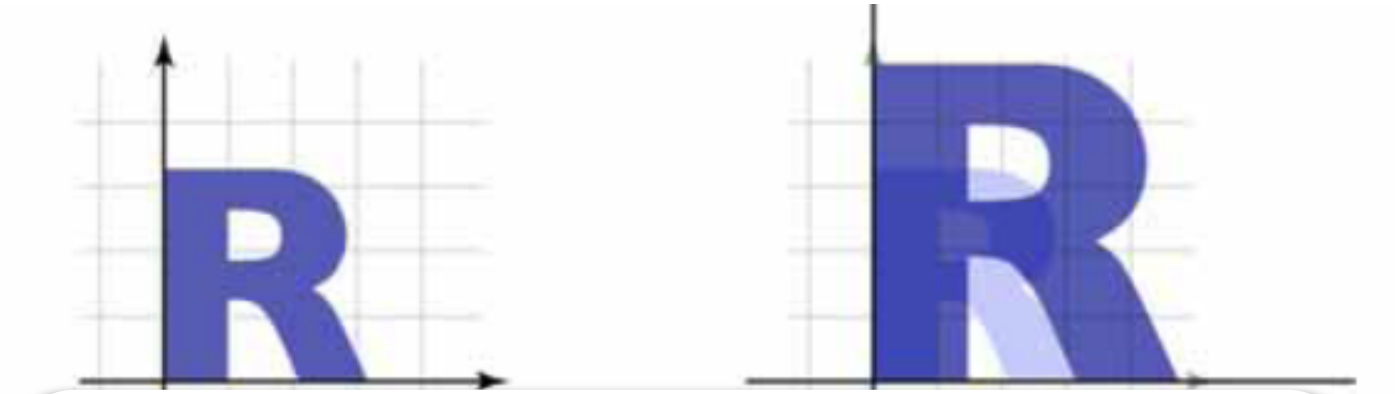
```
public void draw(float dt) {
    Affine2 oTran = new Affine2();
    oTran.setToTranslation(object.getPosition());
    Affine2 wtran = new Affine2();
    Vector2 wPos = viewWindow.getPosition();
    wTran.setToTranslation(-wPos.x,-wPos.y);
    oTran.mul(wTran);
    spriteBatch.begin();
        spriteBatch.draw(image,width,height,oTran);
    spriteBatch.end();
}
```

scrolling support

Transform Gallery

- Uniform Scale: $\begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} sx \\ sy \end{bmatrix}$

$$\begin{bmatrix} 1.5 & 0 \\ 0 & 1.5 \end{bmatrix}$$



```
affine.setToScaling(s,s);
```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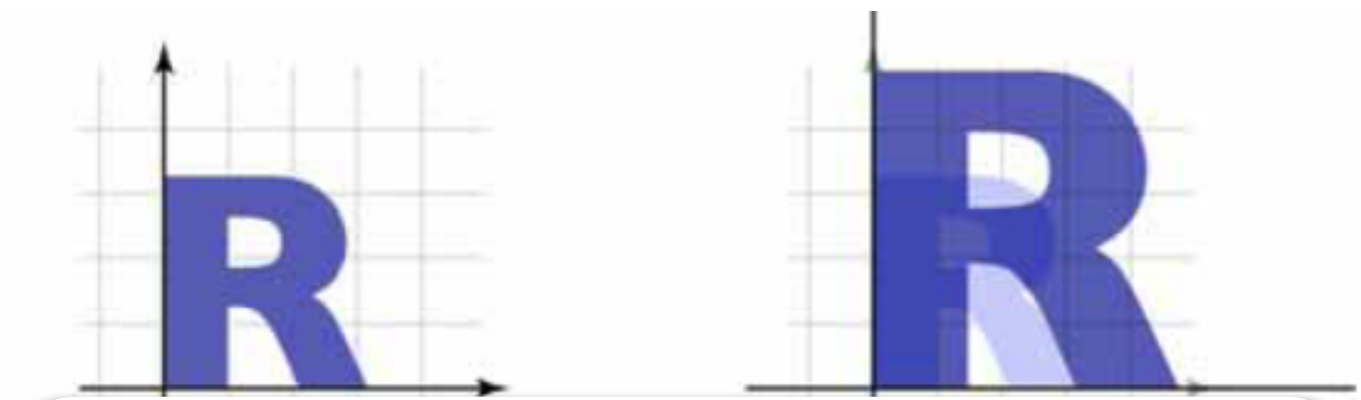
Transform Gallery

- Uniform Scale: $\begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} sx \\ sy \end{bmatrix}$

Represent as 2x2 matrix

$$\begin{bmatrix} 1.5 & 0 \\ 0 & 1.5 \end{bmatrix}$$



```
affine.setToScaling(s,s);
```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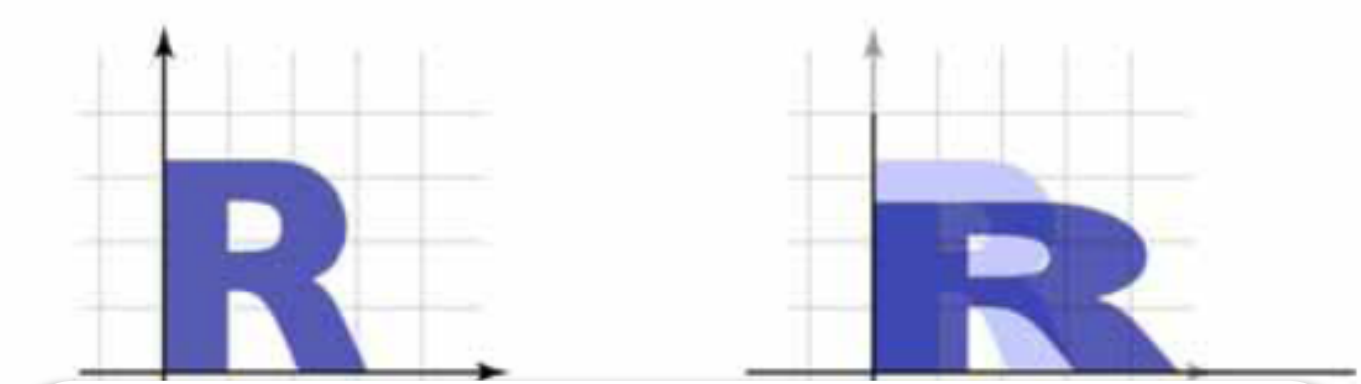
Matrix Transform Gallery

- Nonuniform Scale: $\begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} s_x x \\ s_y y \end{bmatrix}$

$$\begin{bmatrix} 1.5 & 0 \\ 0 & 0.8 \end{bmatrix}$$



```
affine.setToScaling(sx,sy);
```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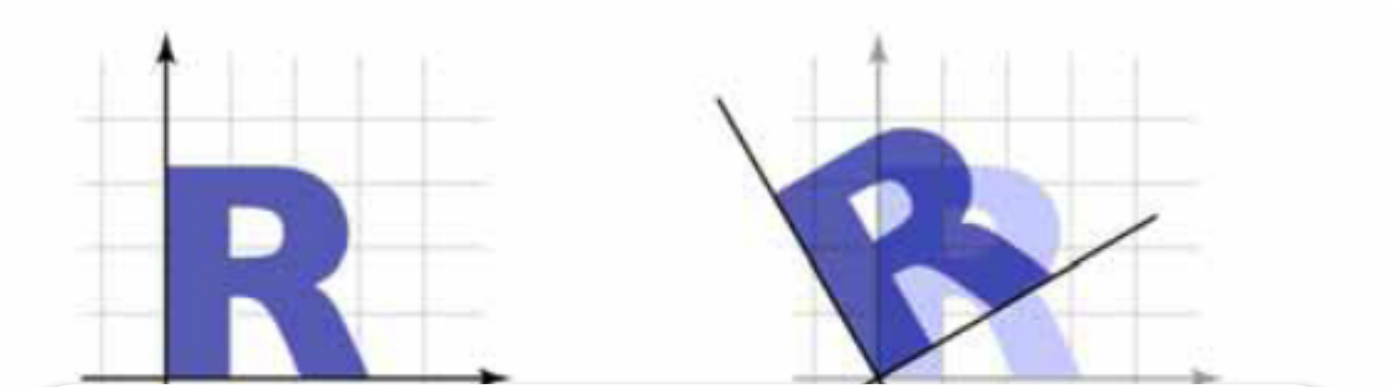
Matrix Transform Gallery

- Rotation:

$$\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} x\cos\theta - y\sin\theta \\ x\sin\theta + y\cos\theta \end{bmatrix}$$

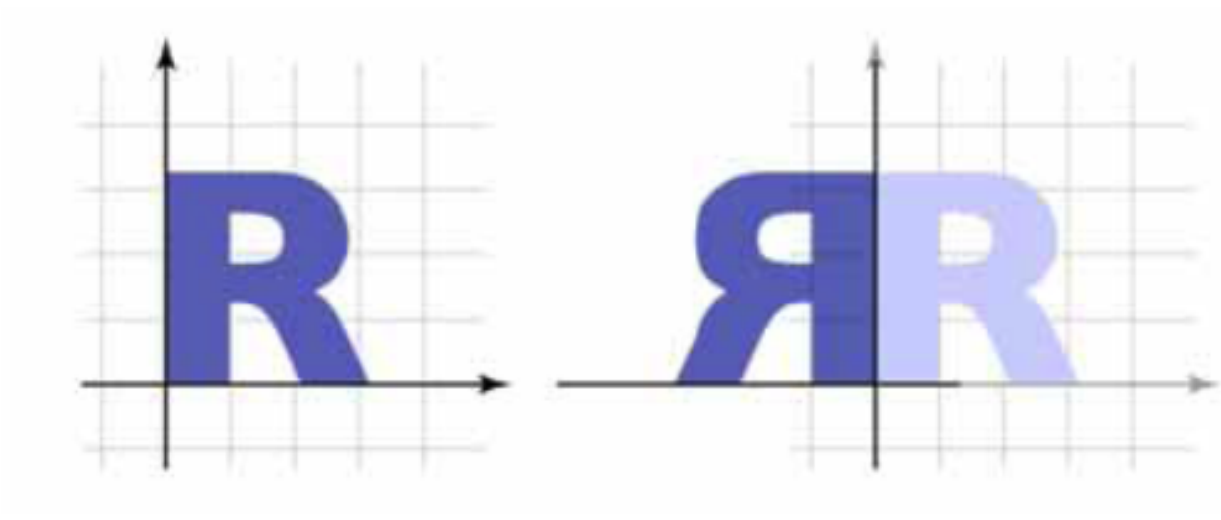
$$\begin{bmatrix} 0.866 & -0.5 \\ 0.5 & 0.866 \end{bmatrix}$$



```
affine.setToRotationRad(angle);
```

Matrix Transform Gallery

- Reflection: $\begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} -x \\ y \end{bmatrix}$
  - View as special case of Scale $\begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}$



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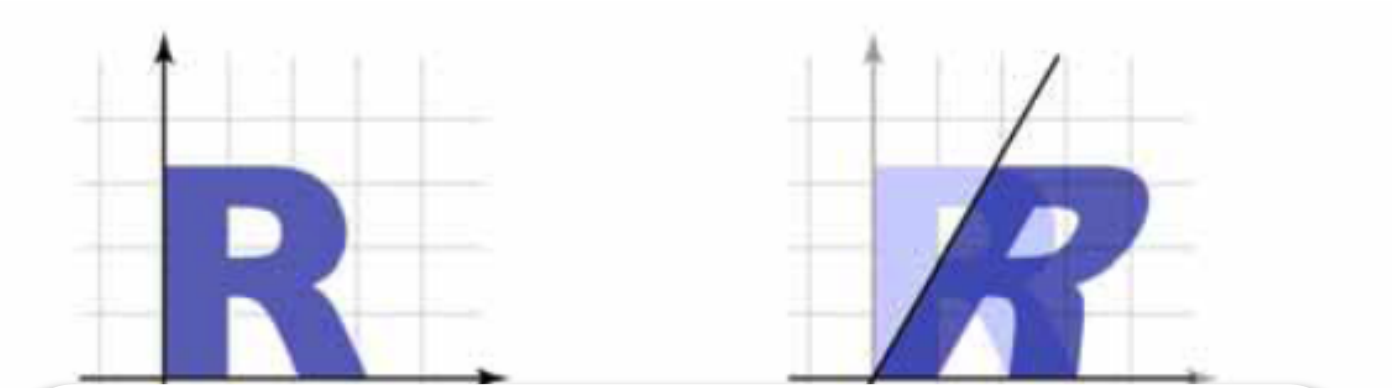
Matrix Transform Gallery

- Shear: $$\begin{bmatrix} 1 & a \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} x + ay \\ y \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0.5 \\ 0 & 1 \end{bmatrix}$$



```
affine.setToShearing(a,1);
```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Translation Revisited

- Translation is **not** a linear transform
  - To be linear, $T(\mathbf{v}+\mathbf{w}) = T(\mathbf{v})+T(\mathbf{w})$
  - Translation transform is $T(\mathbf{v}) = \mathbf{v}+\mathbf{u}$
  - $T(\mathbf{v})+T(\mathbf{w}) = (\mathbf{v}+\mathbf{u})+(\mathbf{w}+\mathbf{u}) = \mathbf{v}+\mathbf{w}+2\mathbf{u} \neq T(\mathbf{v}+\mathbf{w})$
- But LibGDX treats it like one
  - `Affine2` transforms support translation
  - `Matrix4` supports `matrix.set(affine)`
- What is going on here?

Homogenous Coordinates

- Add an **extra dimension** to the calculation.
  - An extra component w for vectors
  - For affine transformations, can keep $w = 1$
  - Add extra row, column to matrices (so 3×3)
- Dimension is for calculation only
  - We are not in 3D-space **yet**
  - 3D transforms need 4D vectors, 4×4 matrices
- Matrix4 because LibGDX supports 3D

Homogenous Coordinates

- Linear transforms have dummy row and column

$$\begin{bmatrix} a & b & 0 \\ c & d & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} ax + by \\ cx + dy \\ 1 \end{bmatrix}$$

- Translation uses extra column

$$\begin{bmatrix} 1 & 0 & t \\ 0 & 1 & s \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x + t \\ y + s \\ 1 \end{bmatrix}$$

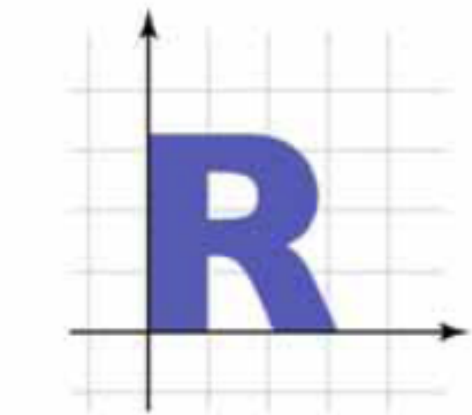
Affine Transforms Revisited

- **Affine**: Linear on homogenous coords
  - Equal to all transforms $T(\mathbf{v}) = \mathrm{M}\mathbf{v}+\mathbf{p}$
  - Treat everything as matrix multiplication
- Why does this work?
  - Area of mathematics called projective geometry
  - Far beyond the scope of this class
- LibGDX hides all the messy details
  - Just stick with `Affine2` class for now

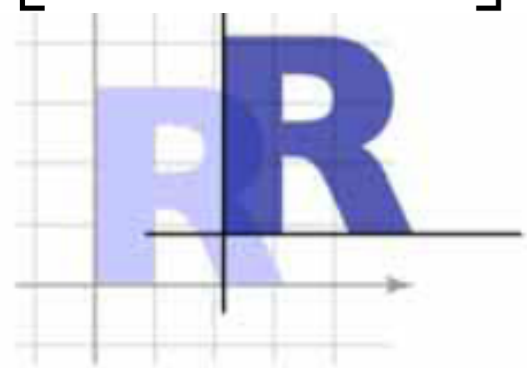
Affine Transform Gallery

- Translation:

$$\begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix}$$



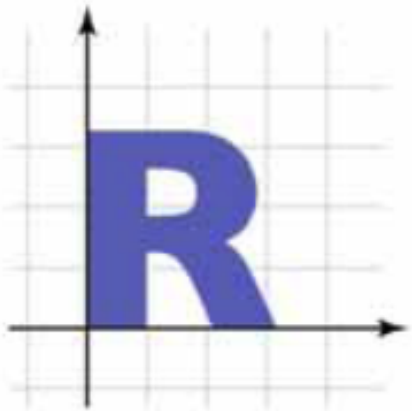
$$\begin{bmatrix} 1 & 0 & 2.15 \\ 0 & 1 & 0.85 \\ 0 & 0 & 1 \end{bmatrix}$$

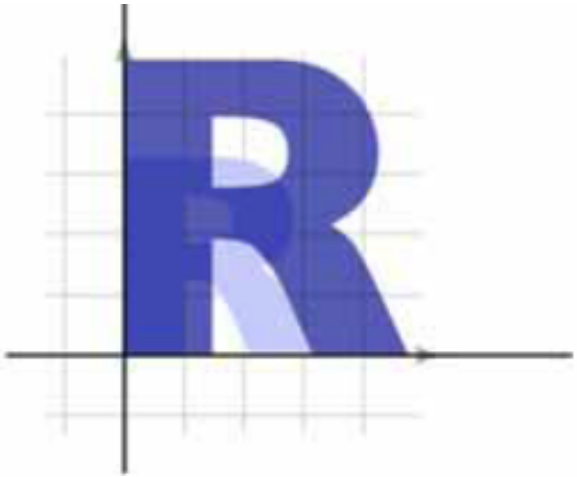


Affine Transform Gallery

- Uniform Scale:

$$\begin{bmatrix} s & 0 & 0 \\ 0 & s & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1.5 & 0 & 0 \\ 0 & 1.5 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

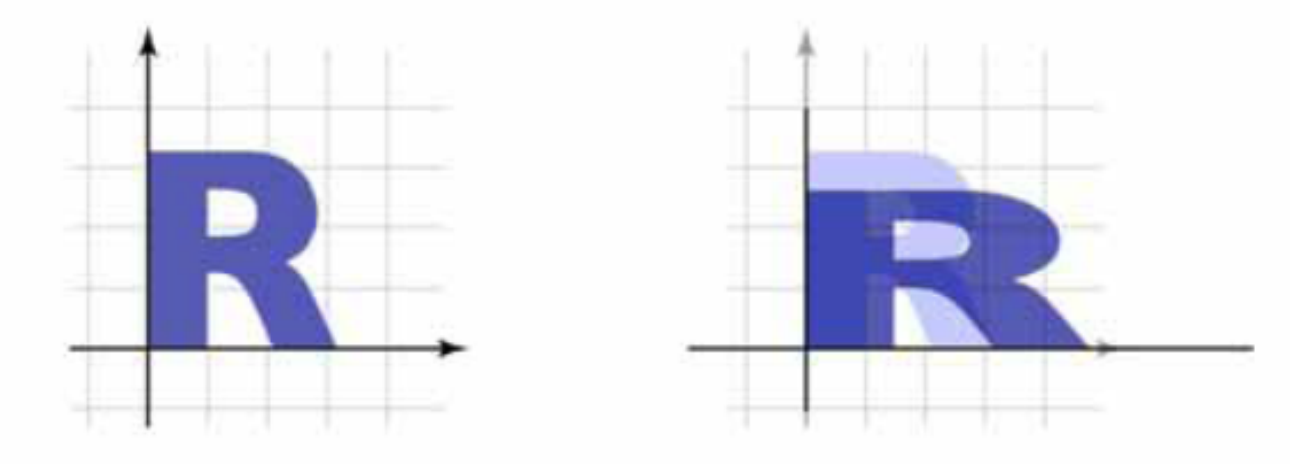




Affine Transform Gallery

- Nonuniform Scale:

$$\begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1.5 & 0 & 0 \\ 0 & 0.8 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



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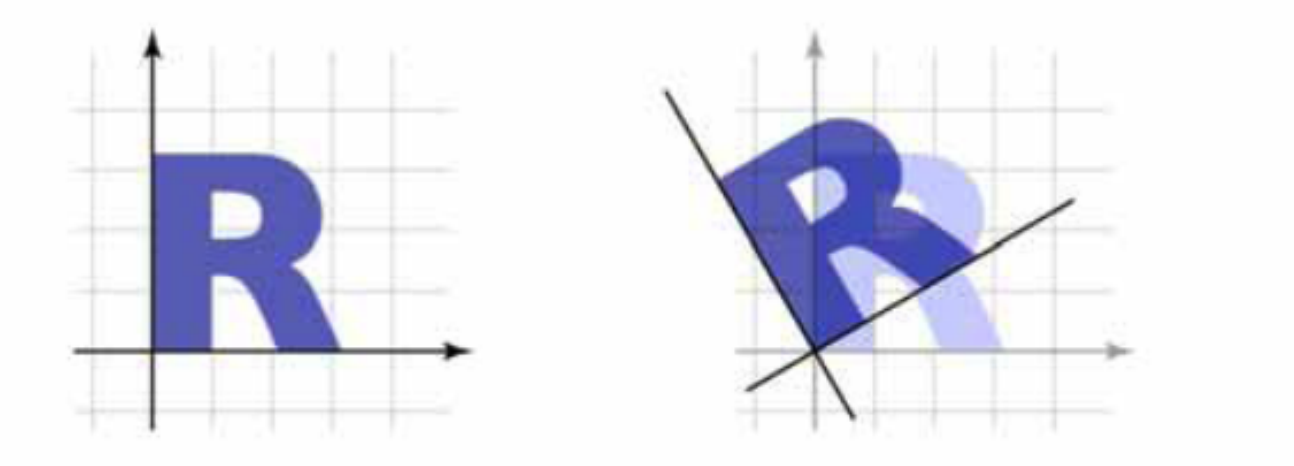
Affine Transform Gallery

- Rotation:

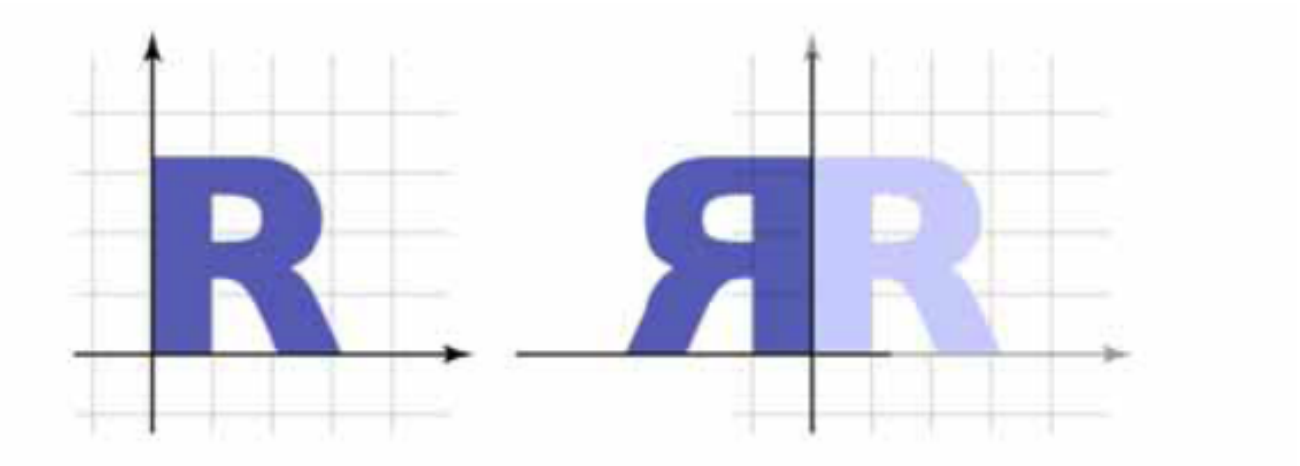
$$\begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.866 & -0.5 & 0 \\ 0.5 & 0.866 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



Affine Transform Gallery

- Reflection:
  - Special case of Scale

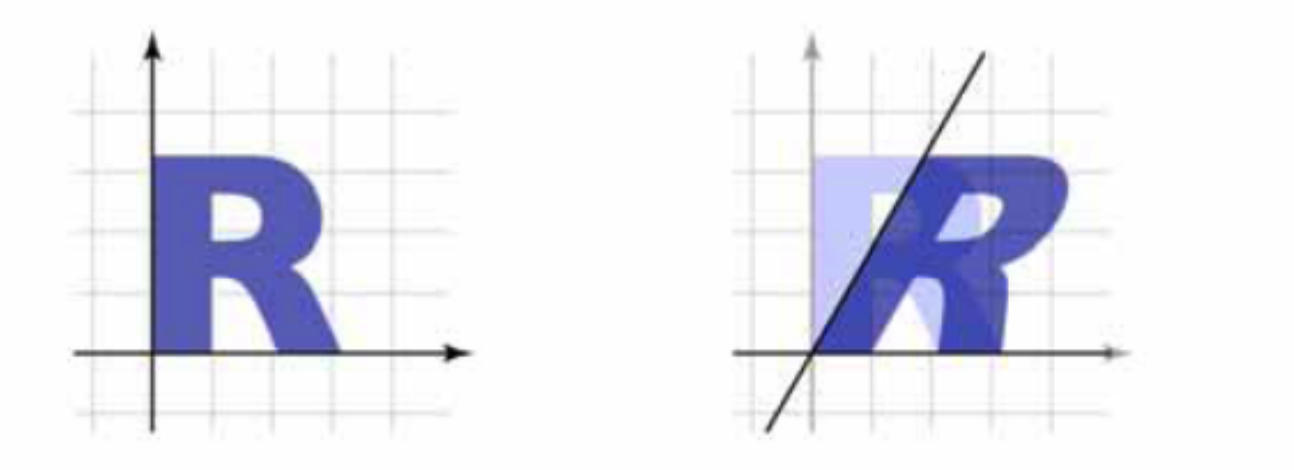
$$\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



Affine Transform Gallery

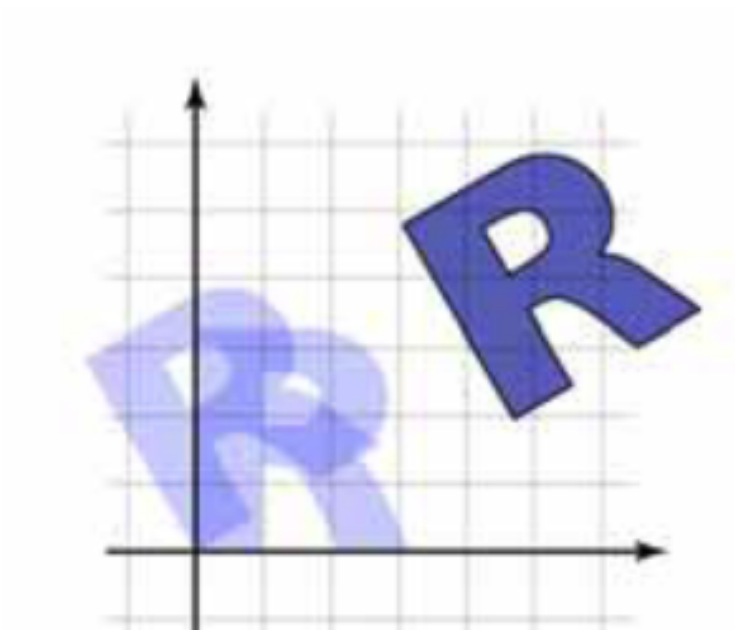
- Shear:

$$\begin{bmatrix} 1 & a & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1 & 0.5 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

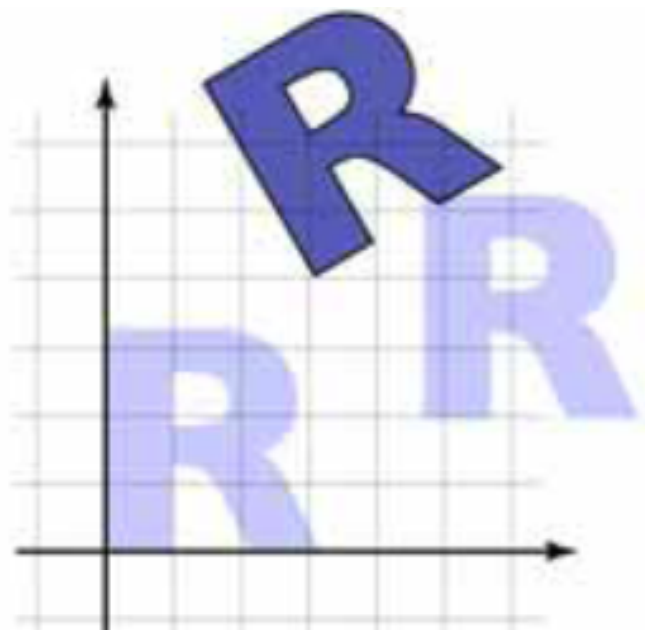


Compositing Transforms

- In general not commutative: order matters!



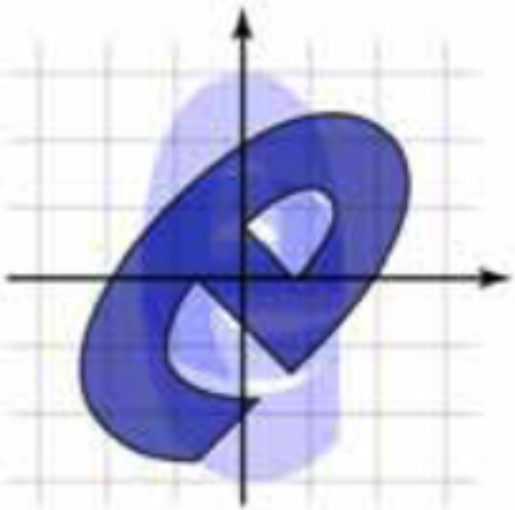
rotate, then translate



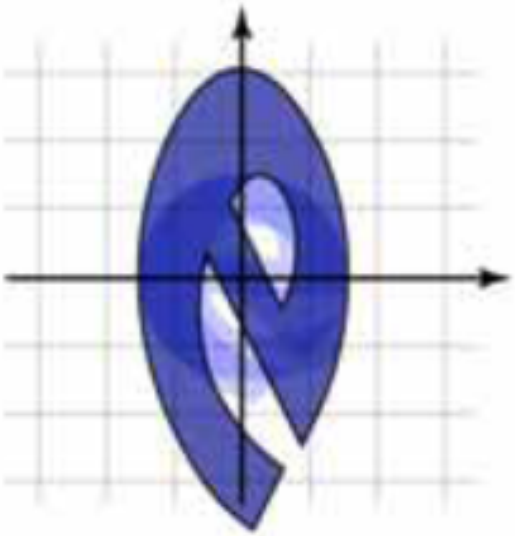
translate, then rotate

Compositing Transforms

- In general not commutative: order matters!



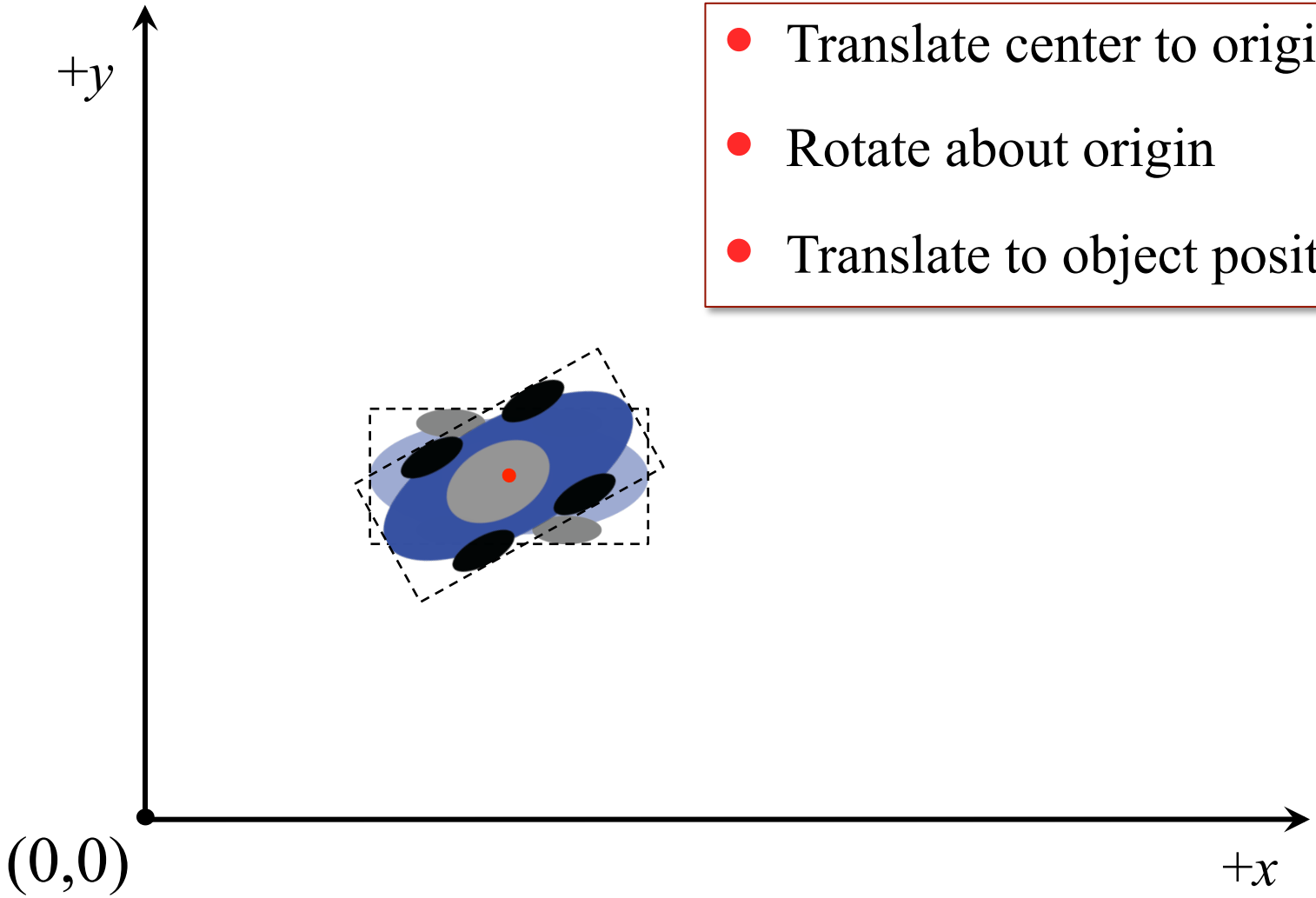
scale, then rotate



rotate, then scale

Rotating Object About Center

- Translate center to origin
- Rotate about origin
- Translate to object position



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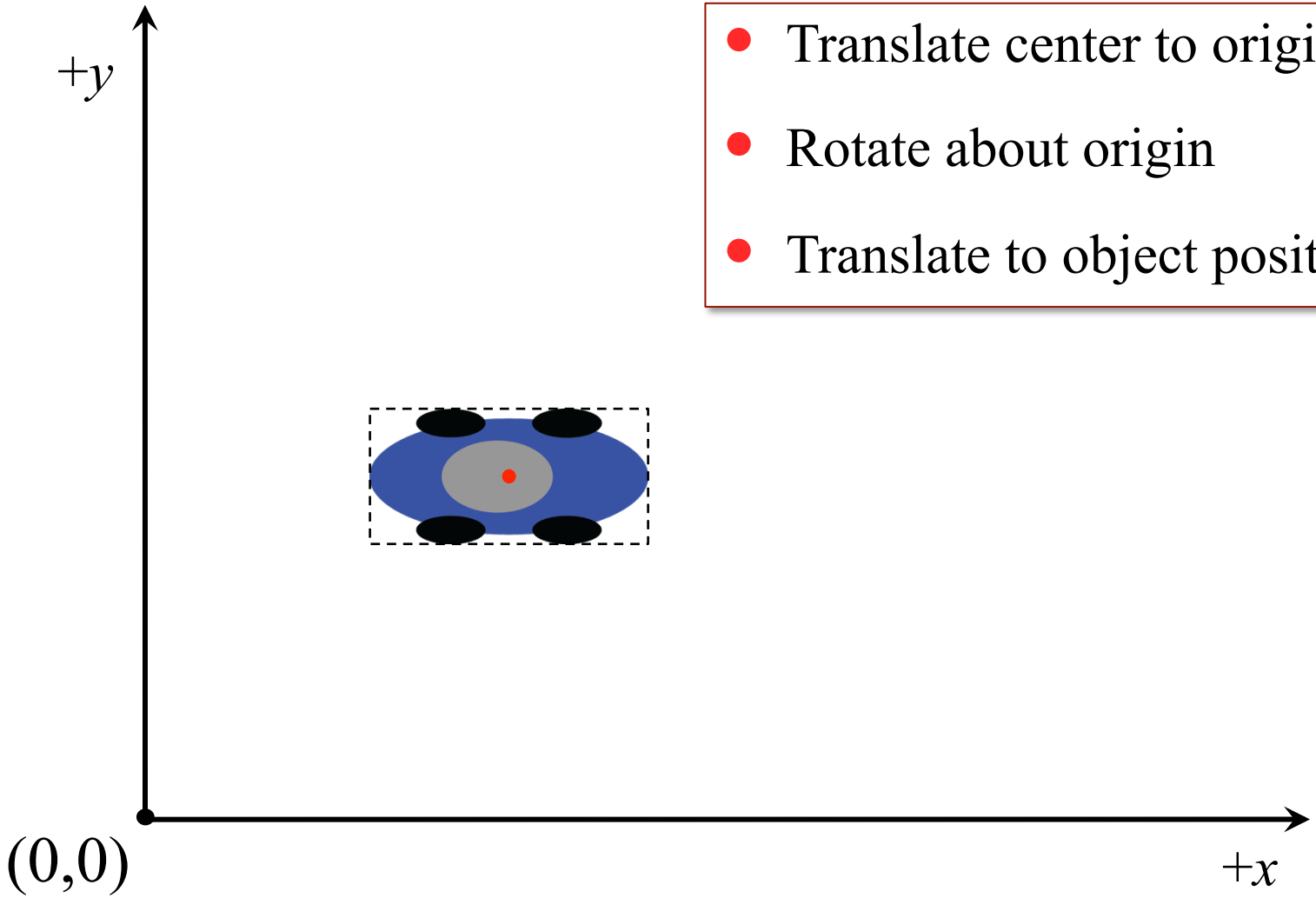
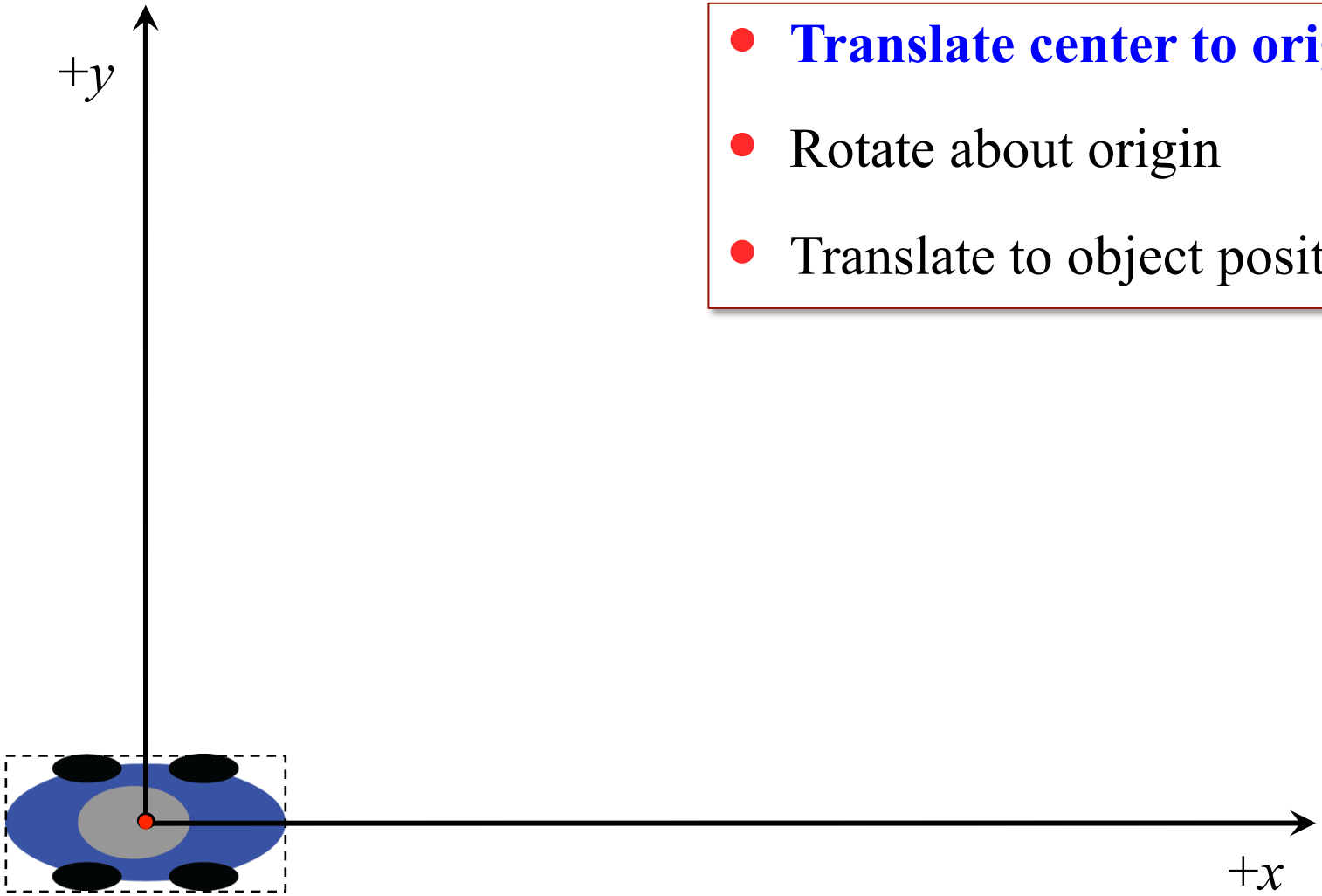
Rotating Object About Center



- Translate center to origin
- Rotate about origin
- Translate to object position

Rotating Object About Center



- **Translate center to origin**
- Rotate about origin
- Translate to object position

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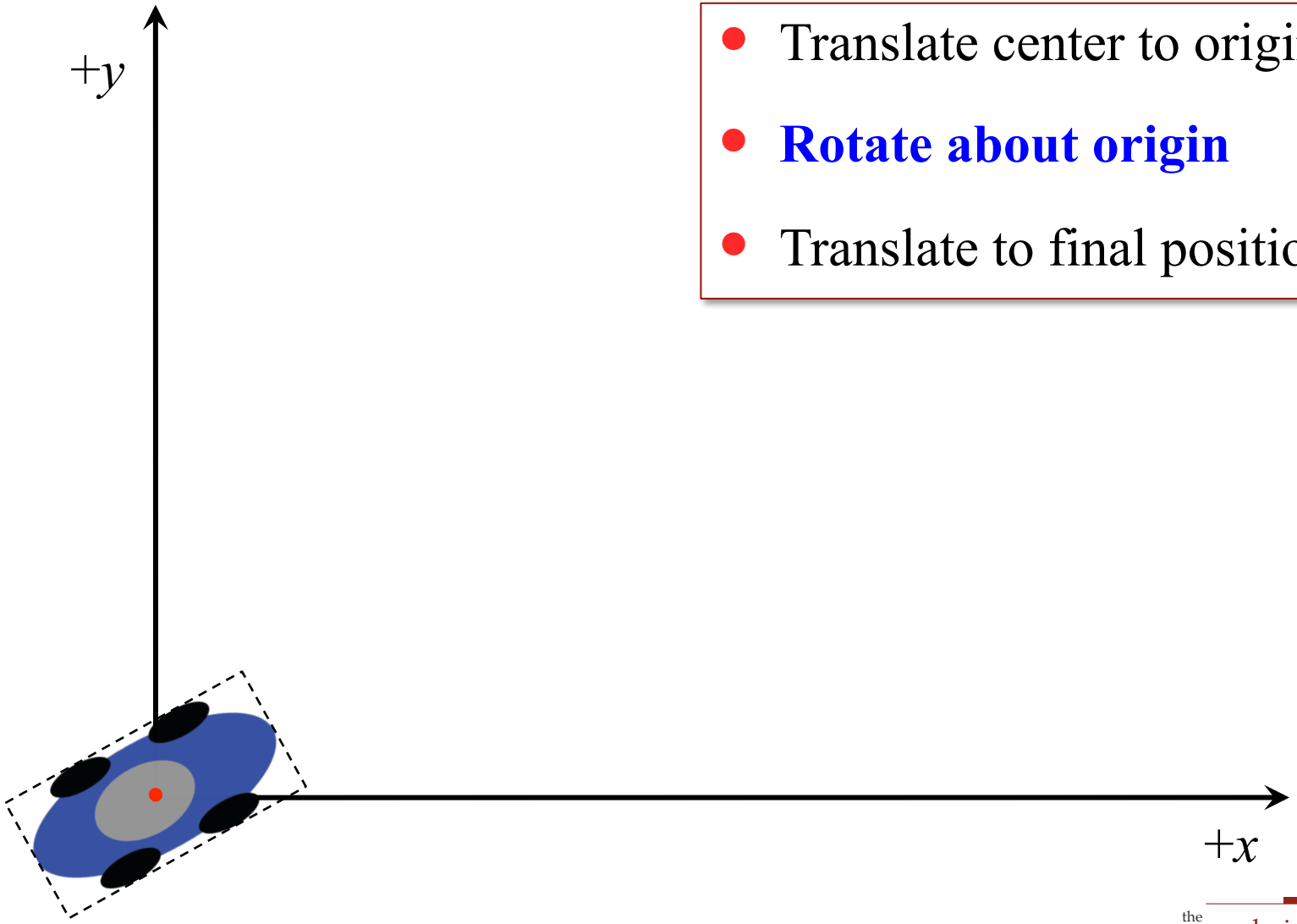
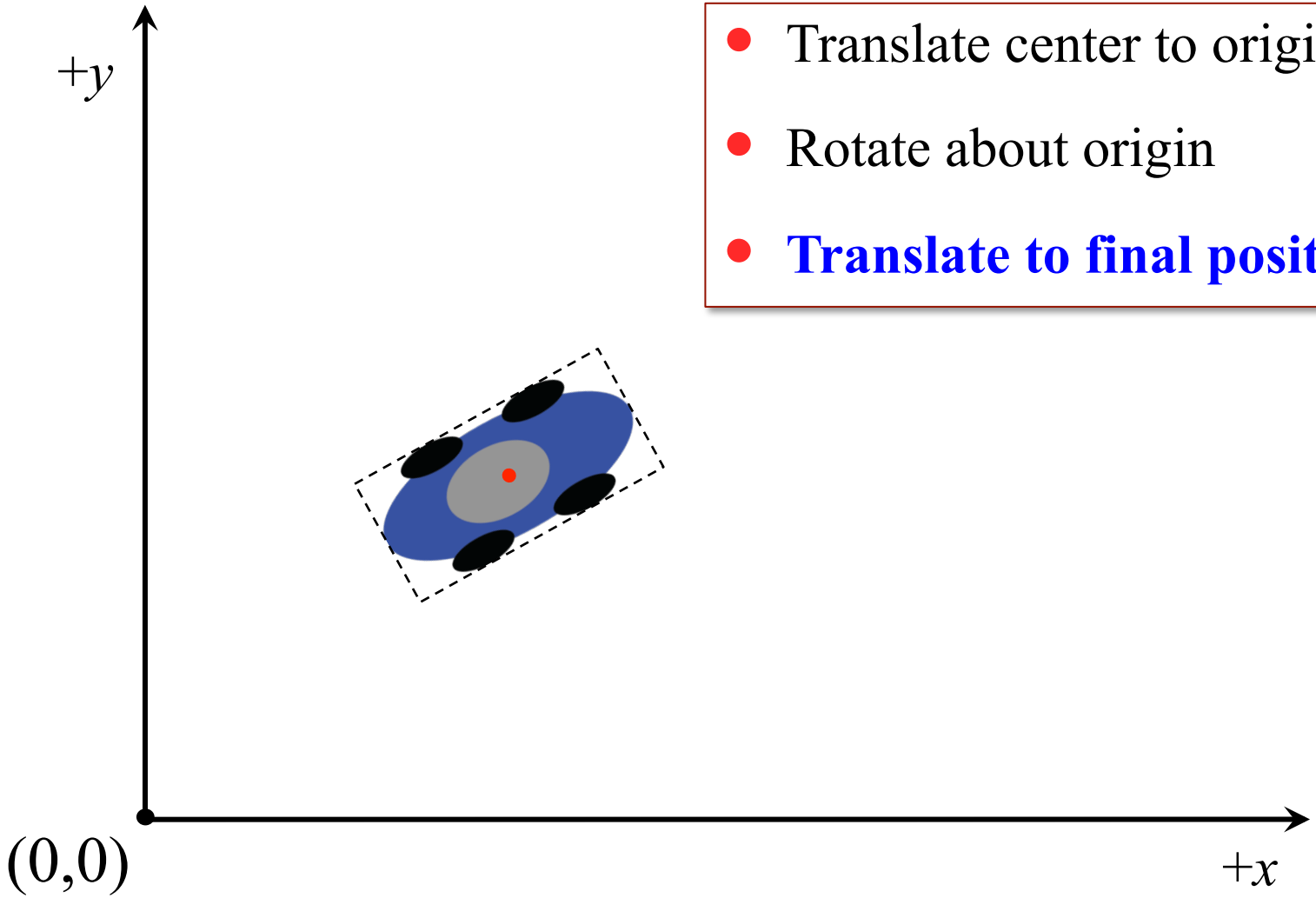
Rotating Object About Center



- Translate center to origin
- **Rotate about origin**
- Translate to final position

Rotating Object About Center

- Translate center to origin
- Rotate about origin
- **Translate to final position**



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A Word About Scaling

- If making smaller, it drops out pixels
  - Suppose $T(\mathbf{v}) = 0.5\mathbf{v}$
  - $(0,0) = T(0,0)$; pixel (0,0) colored from (0,0) in file
  - $(0,1) = T(0,2)$; pixel (0,1) colored from (0,2) in file
- But if making larger, it duplicates pixels
  - Suppose $T(\mathbf{v}) = 2\mathbf{v}$
  - $(0,1) = T(0,0.5)$; pixel (0,1) colored from (0,1) in file
  - $(0,1) = T(0,1)$; pixel (0,2) colored from (0,1) in file
- This can lead to *jaggies*

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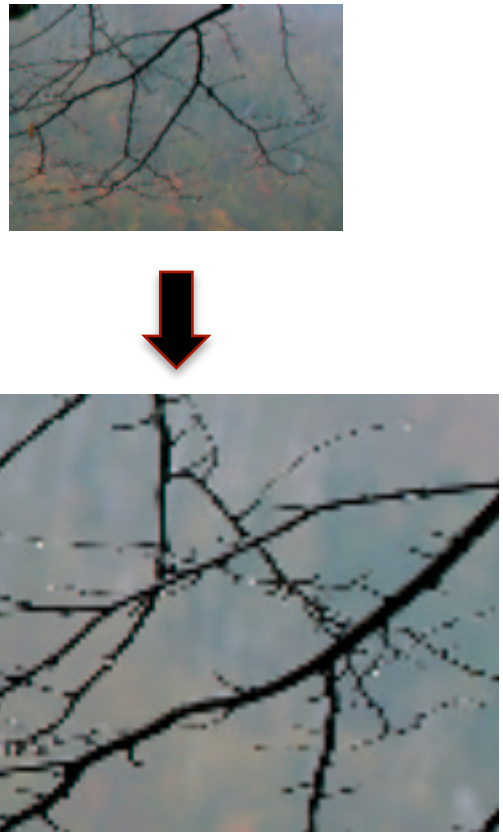
Scaling and Jaggies

- Jaggies: Image is blocky
- Possible to smooth image
  - Done through blurring
  - In **addition** to transform
  - *Some* graphic card support
- Solution for games
  - Shrinking is okay
  - Enlarging not (always) okay
  - Make sprite large as needed



Summary

- Drawing is all about coordinate systems
  - Object coords: Coordinates of pixels in image file
  - Screen coords: Coordinates of screen pixels
- Transforms alter coordinate systems
  - "Multiply" image by matrix to distort them
  - Multiply transforms together to combine them
    - Matrices are not commutative
    - Later transforms go on "the right"

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