

Lecture 15

2D Sprite Graphics

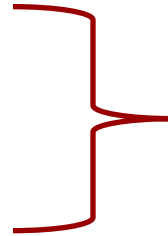
Graphics Lectures

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

Graphics Lectures

- Drawing Images

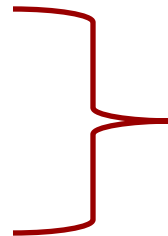
- SpriteBatch interface
- Coordinates and Transforms



bare minimum
to draw graphics

- Drawing Perspective

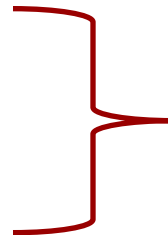
- Camera
- Projections



side-scroller vs.
top down

- Drawing Primitives

- Color and Textures
- Polygons



necessary for
lighting & shadows

Graphics Lectures

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

No **Animation**:
For AI Lectures

Graphics Lectures

- **Drawing Images**

- SpriteBatch interface
- Coordinates and Transforms



bare minimum
to draw graphics

- **Drawing Perspective**

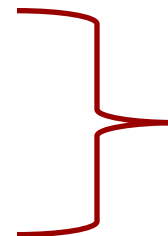
- Camera
- Projections



side-scroller vs.
top down

- **Drawing Primitives**

- Color and Textures
- Polygons



necessary for
lighting & shadows

Take Away for Today

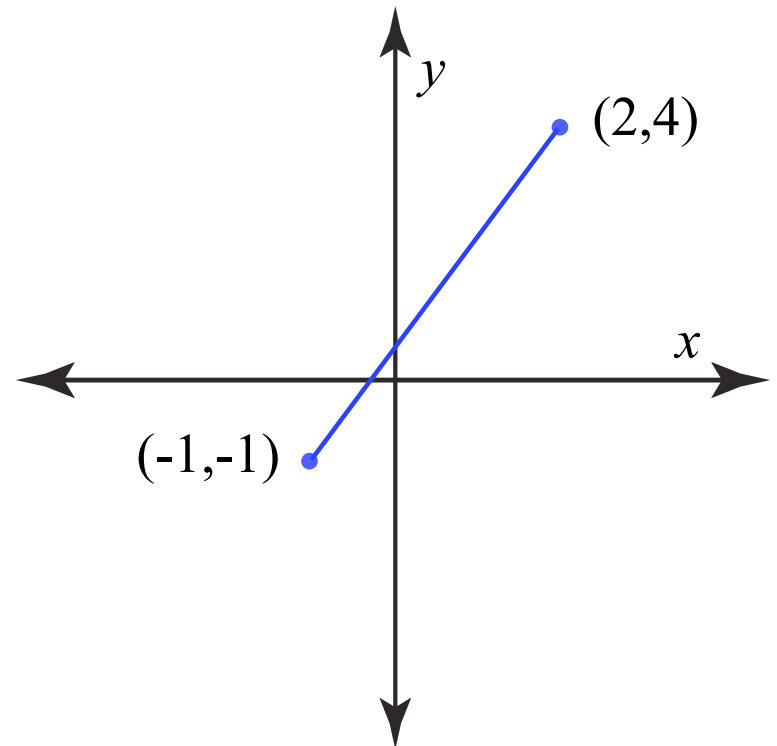
- **Coordinate Spaces** and drawing
 - What is screen space? Object space?
 - How do we use the two to draw objects?
 - Do we need any other spaces as well?
- **Drawing Transforms**
 - What is a drawing transform?
 - Describe the classic types of transforms.
 - List how to use transforms in a game.

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

Drawing in 2 Dimensions

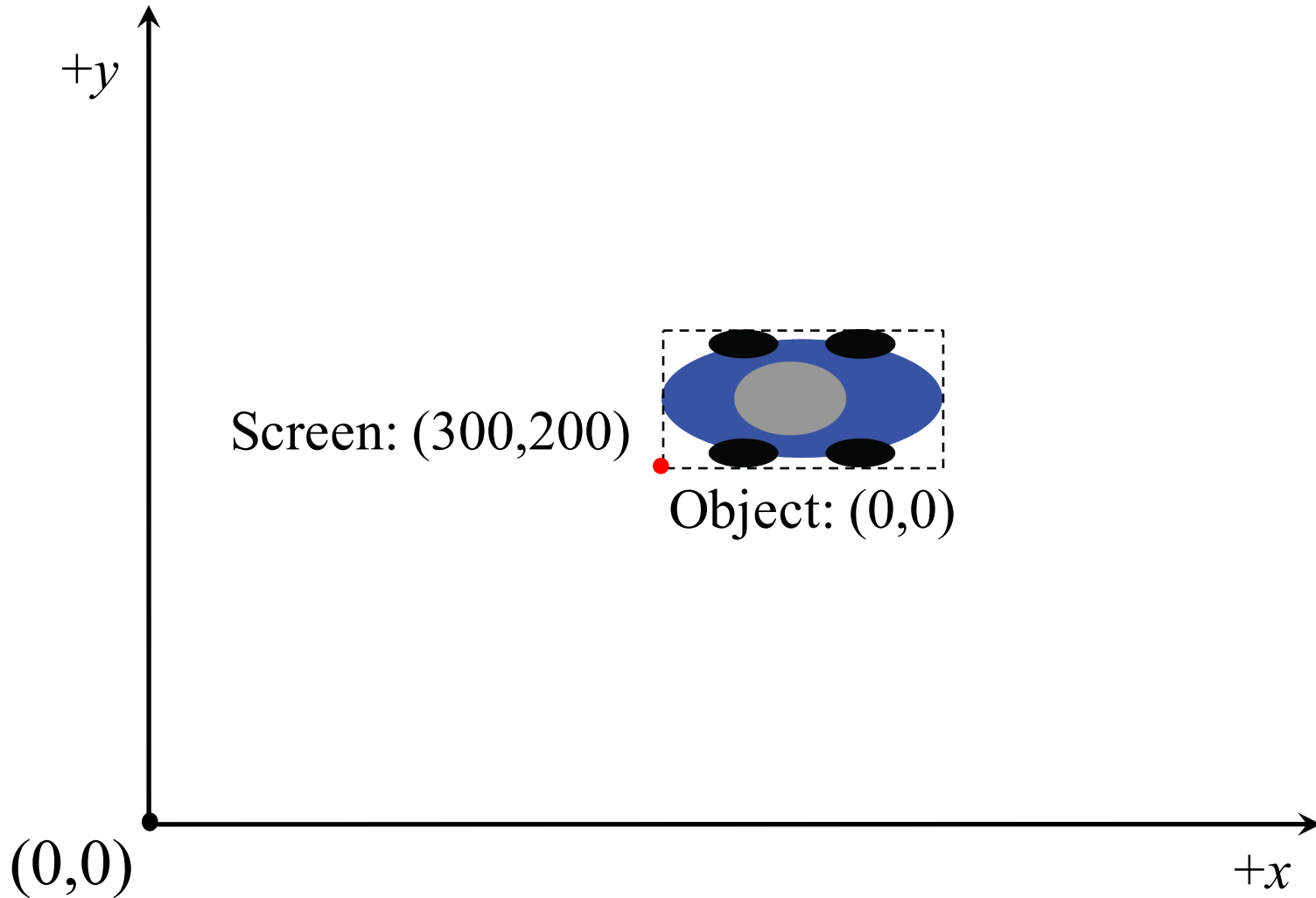
- Use **coordinate systems**
 - Each pixel has a coordinate
 - Draw something at a pixel by
 - Specifying what to draw
 - Specifying where to draw
- Do we draw each pixel?
 - Use a **drawing API**
 - Given an image; does work
 - What LibGDX gives us



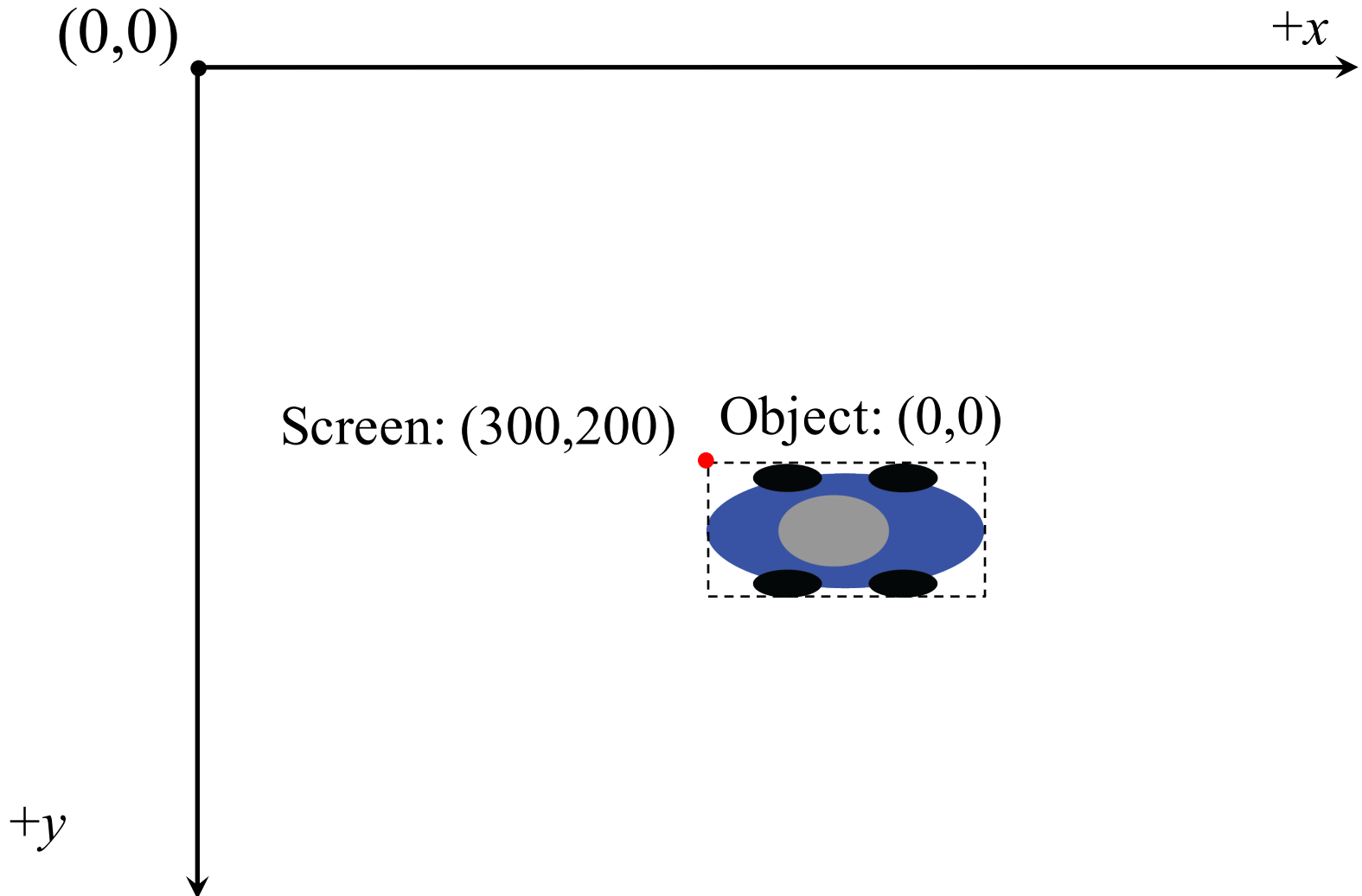
Sprite Coordinate Systems

- **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

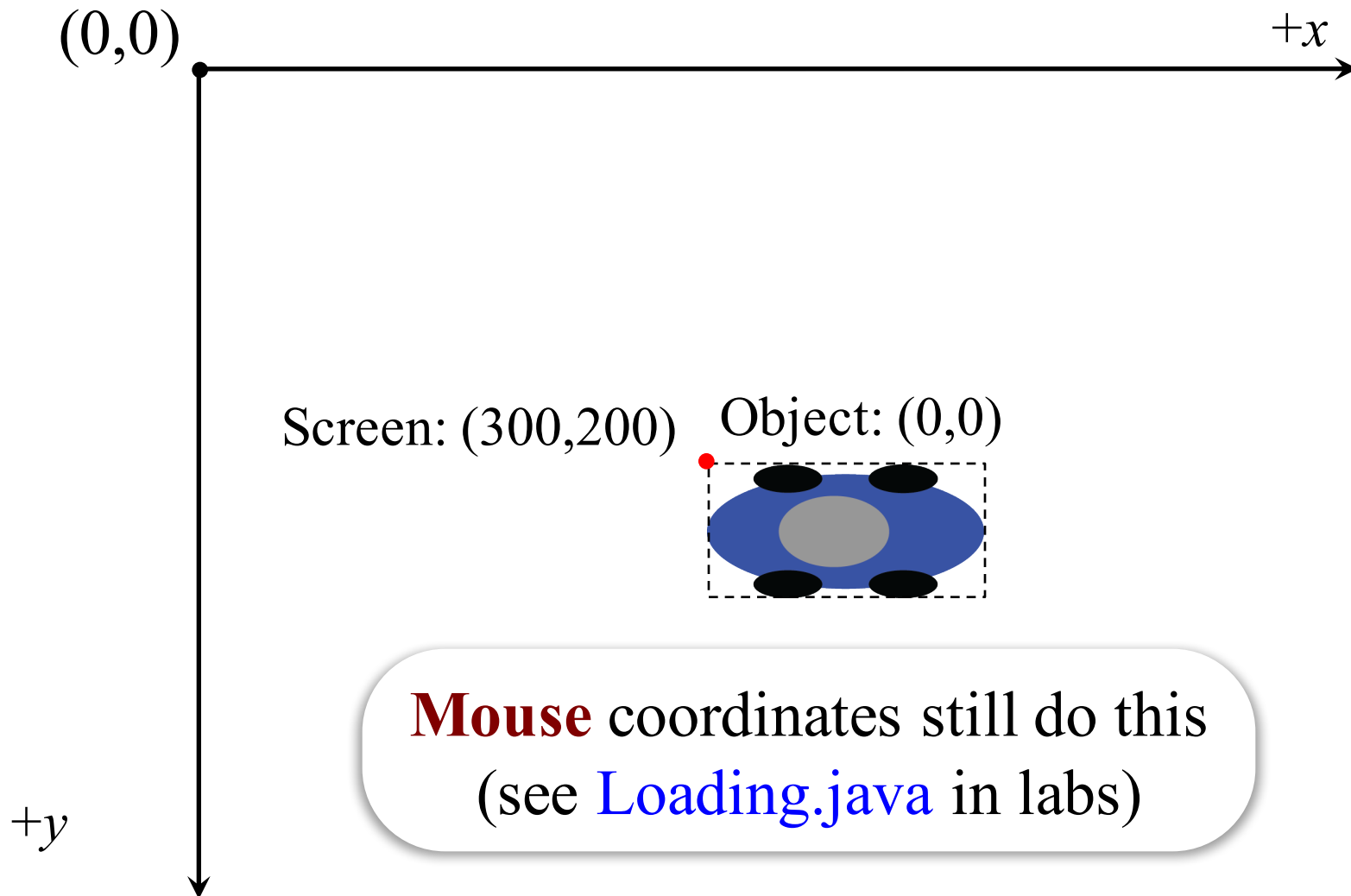
Sprite Coordinate Systems



Historical Coordinate Systems



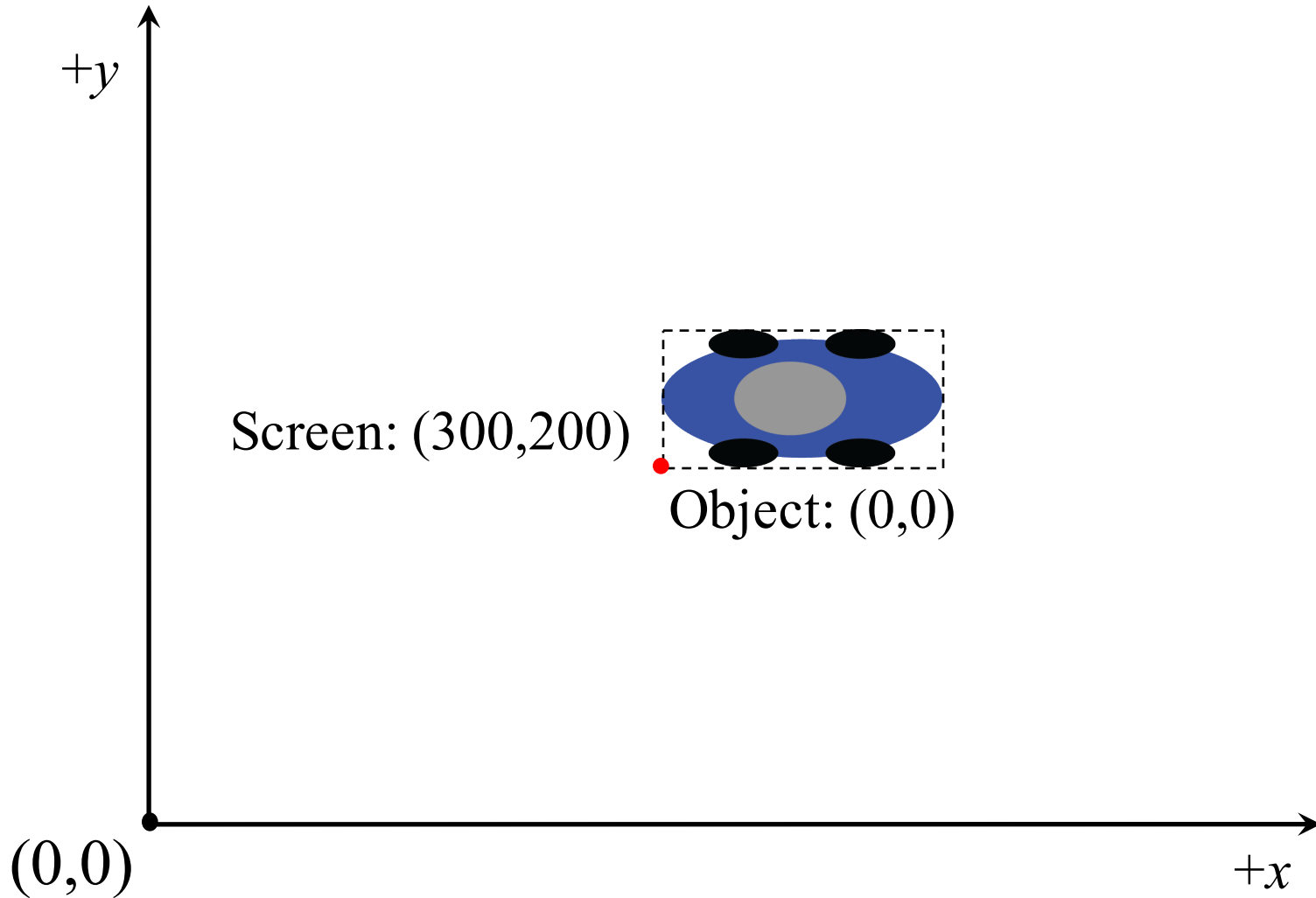
Historical Coordinate Systems



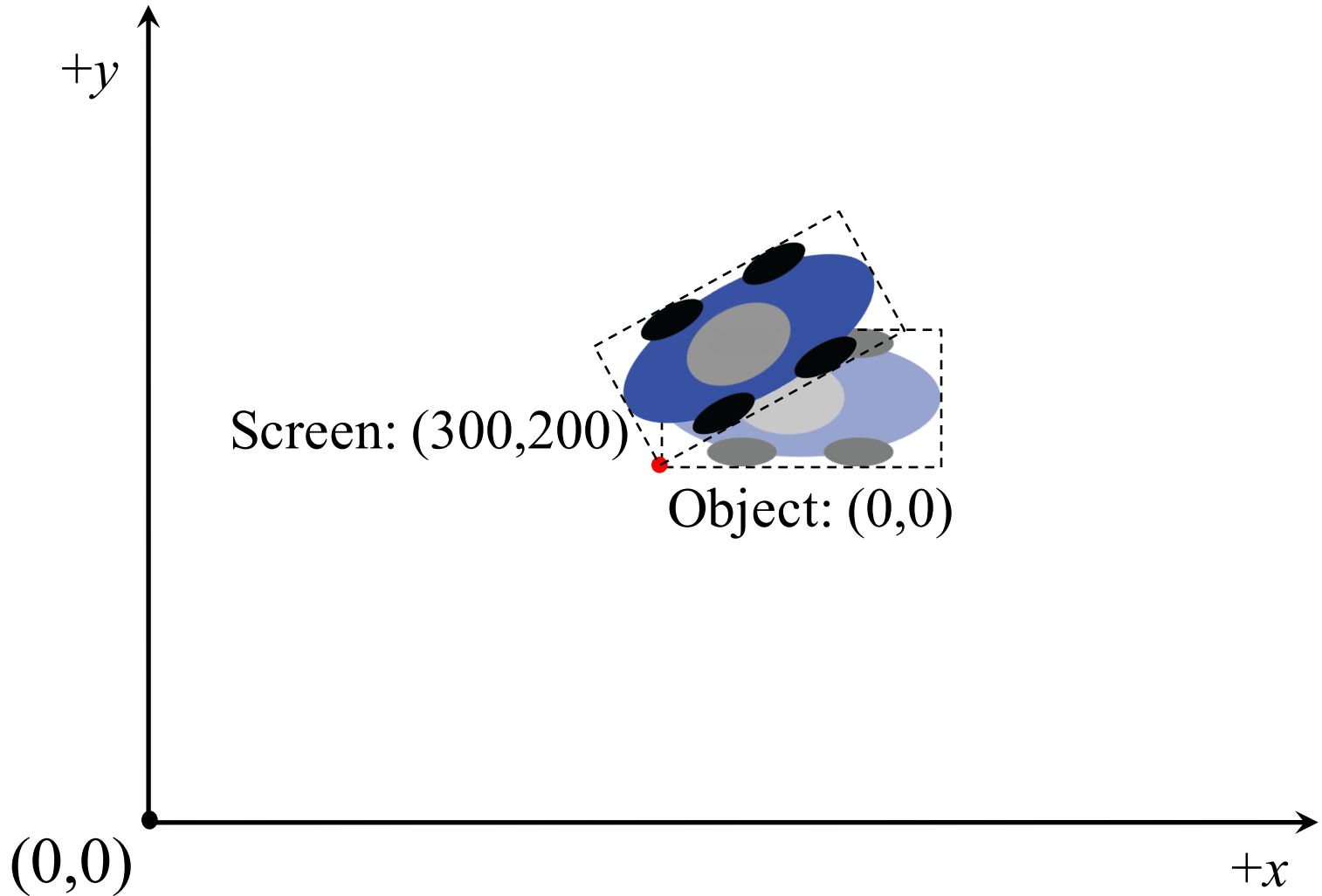
Drawing Sprites

- **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

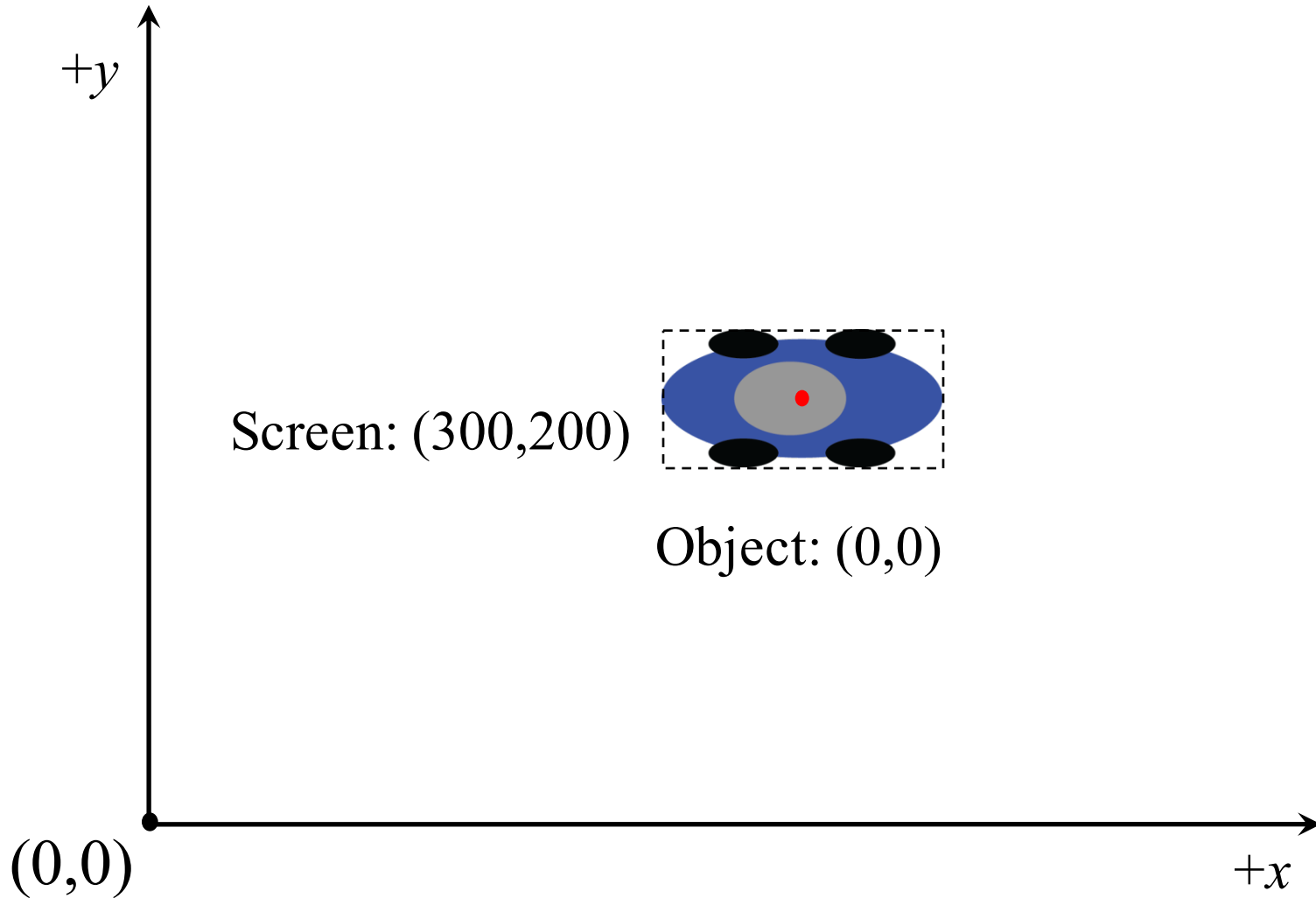
Sprite Coordinate Systems



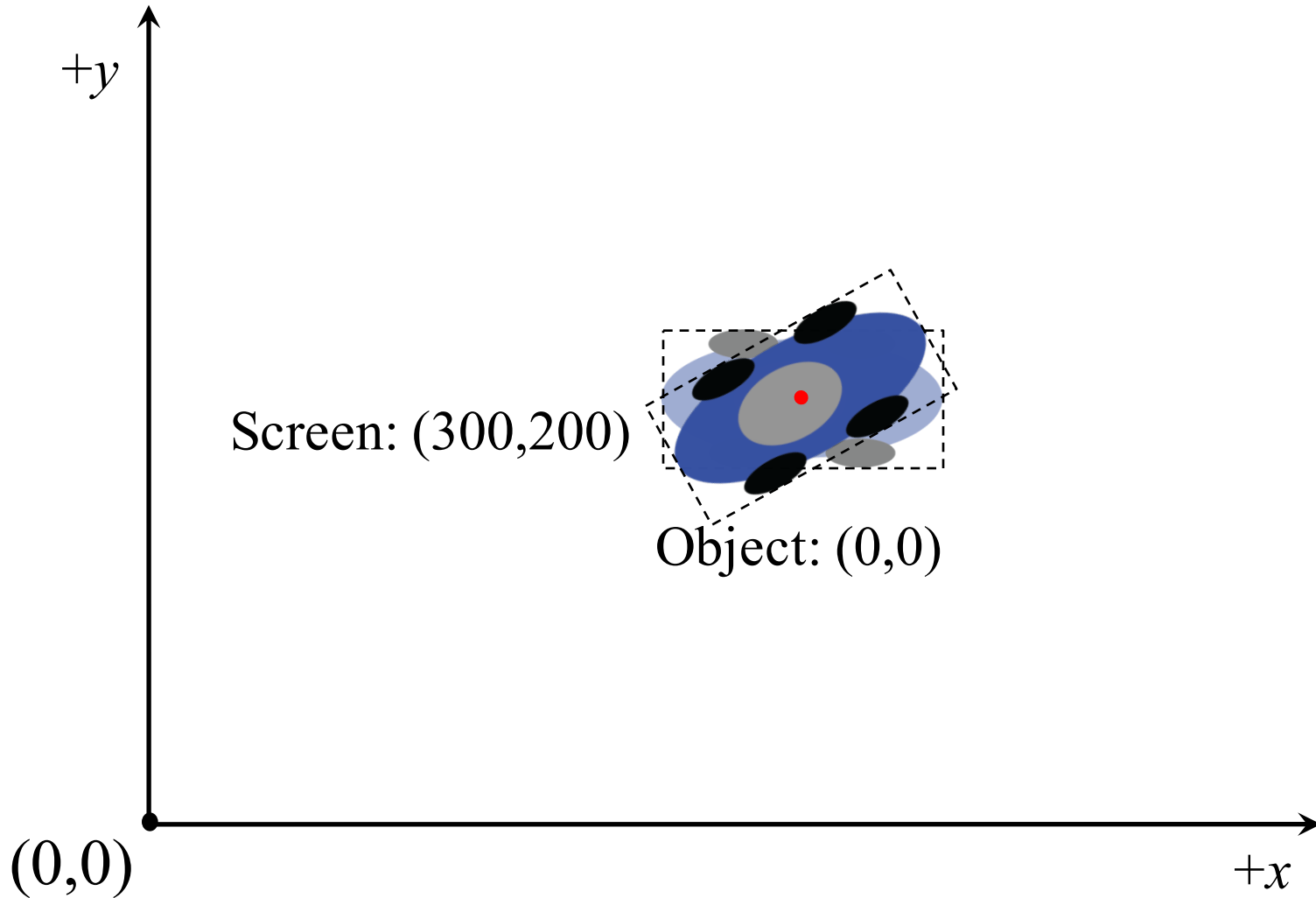
Sprite Coordinate Systems



Sprite Coordinate Systems

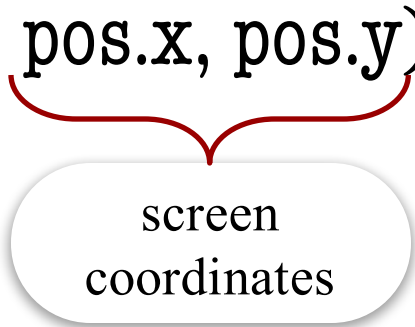


Sprite Coordinate Systems



Drawing with SpriteBatch

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



screen
coordinates

2D Transforms

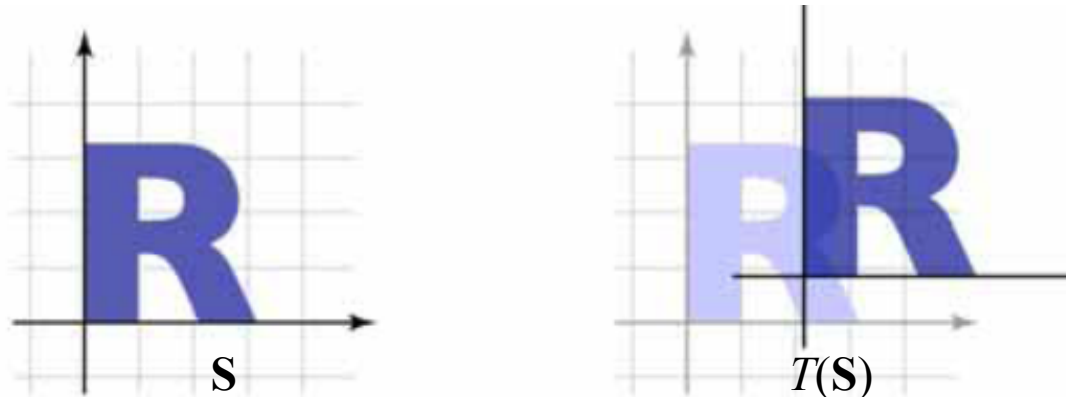
- A function $T : \mathbb{R}^2 \rightarrow \mathbb{R}^2$
 - “Moves” one set of points to another set of points
 - Transforms one “coordinate system” to another
 - The new coordinate system is the distortion
- **Idea:** Draw on paper and then “distort” it
 - **Examples:** Stretching, rotating, reflecting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

The “Drawing Transform”

- T : object coords \rightarrow 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 $T(S)$

Example: Translation

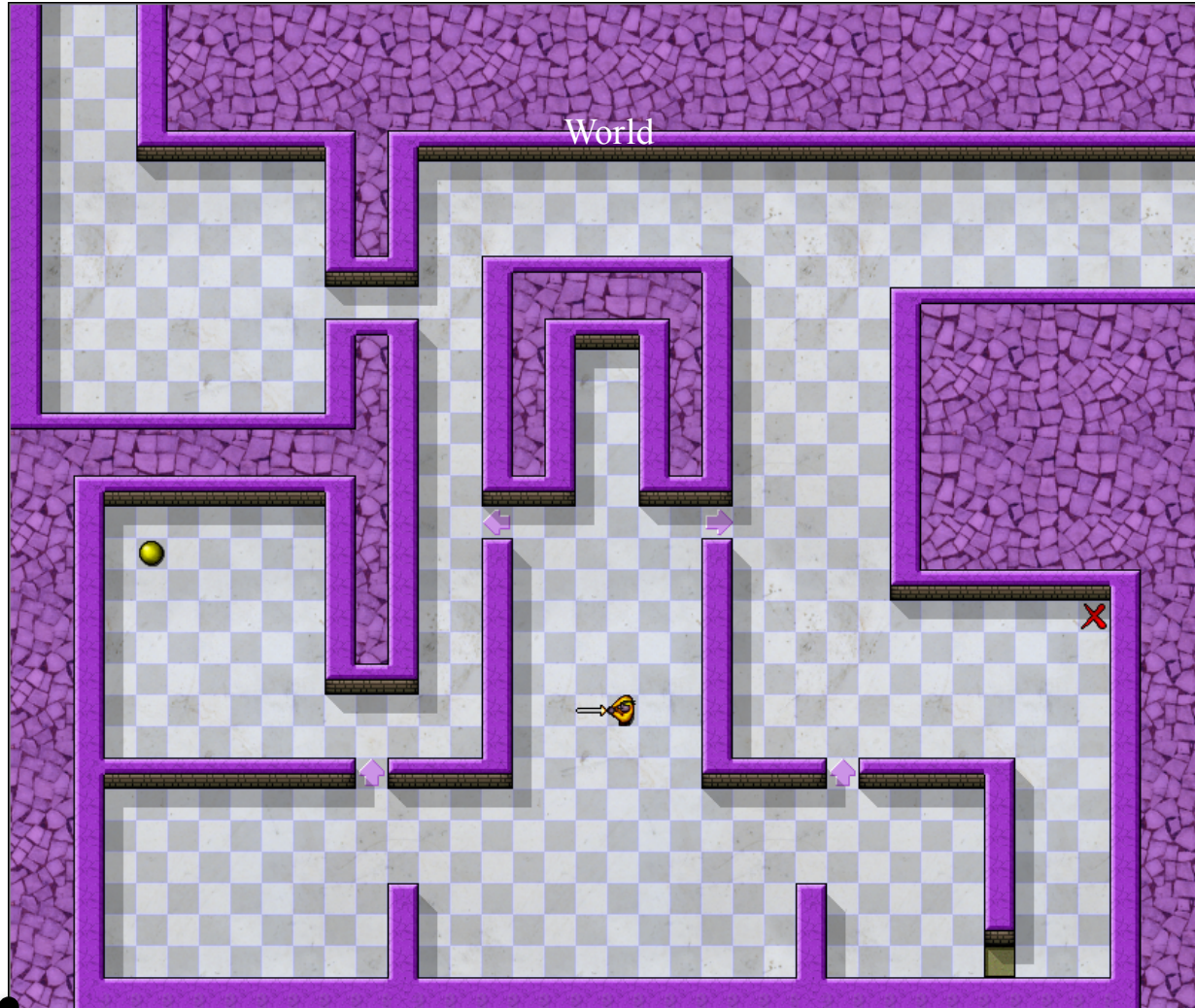
- Simplest transformation: $T(\mathbf{v}) = \mathbf{v} + \mathbf{u}$
 - Shifts object in direction \mathbf{u}
 - Distance shifted is magnitude of \mathbf{u}
- Used to place objects on screen
 - By default, object origin is screen origin
 - $T(\mathbf{v}) = \mathbf{v} + \mathbf{u}$ places object origin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



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

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

Scrolling: Practical Concerns

- Many objects will exist 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)

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

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
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Only supports a
TextureRegion??

Matrix4

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- Only use this if you must
 - e.g. Transforming fonts
 - See GameCanvas in Lab1

Positioning in LibGDX

```
public void draw(float dt) {  
  
    Vector2 pos = object.getPosition();  
  
  
  
    spriteBatch.begin();  
        spriteBatch.draw(image, pos.x, pos.y);  
    spriteBatch.end();  
}
```

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???

Positioning in LibGDX

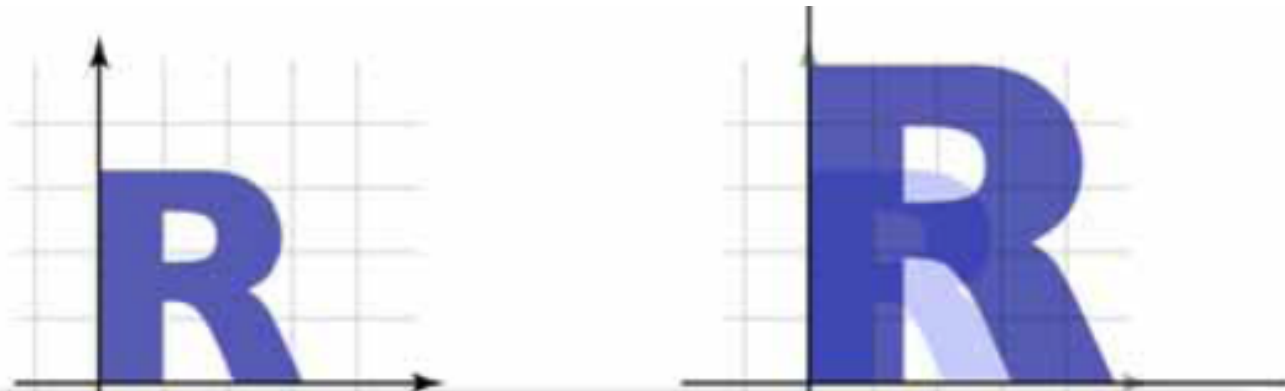
```
public void draw(float dt) {  
    Affine2 oTran = new Affine2();  
    oTran.setToTranslation(object.getPosition());  
    Affine2 wTran = new Affine2();  
    Vector2 wPos = viewWindow.getPosition();  
    wTran.setToTranslation(-wPos.x,-wPos.y);  
    oTran.mul(wTran);  
    spriteBatch.begin();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

scrolling
support

Transform Gallery

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

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



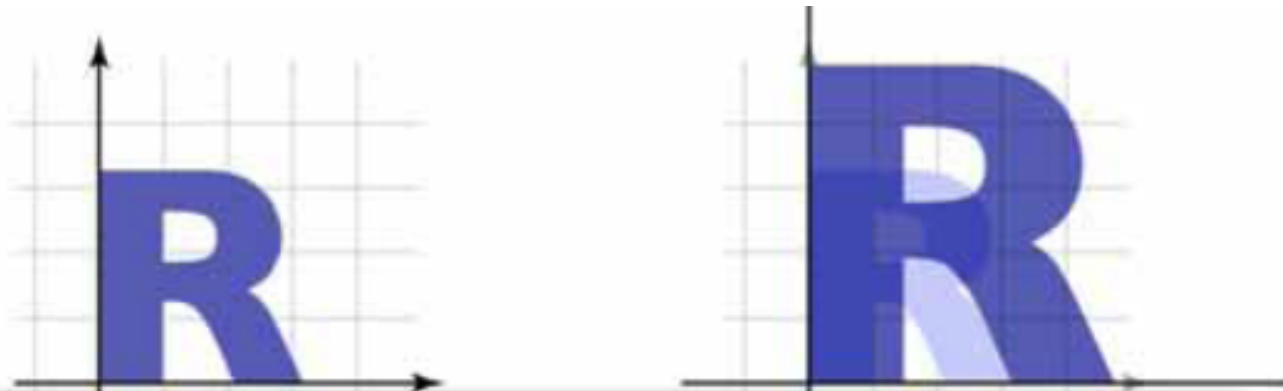
```
affine.setToScaling(s,s);
```

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

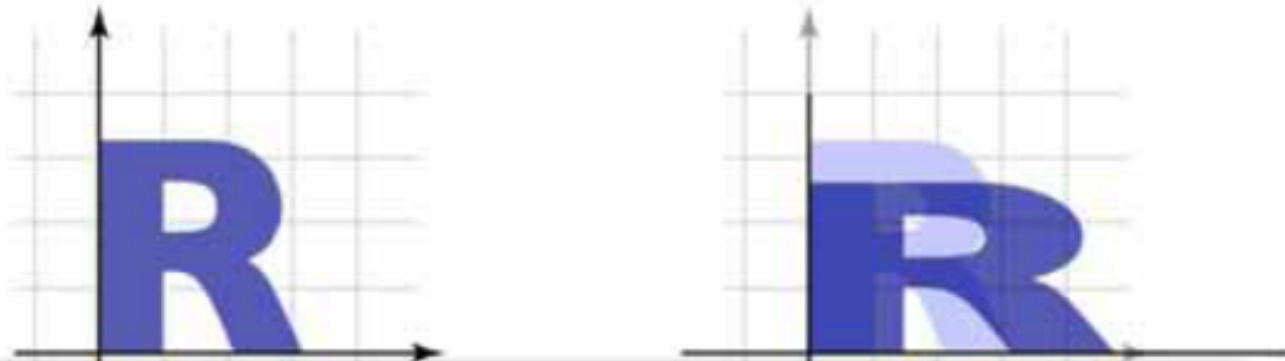
$$\begin{bmatrix} 1.5 & 0 \\ 0 & 1.5 \end{bmatrix}$$



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

Matrix Transform Gallery

- Nonuniform Scale:
$$\begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} s_x x \\ s_y y \end{bmatrix}$$
$$\begin{bmatrix} 1.5 & 0 \\ 0 & 0.8 \end{bmatrix}$$

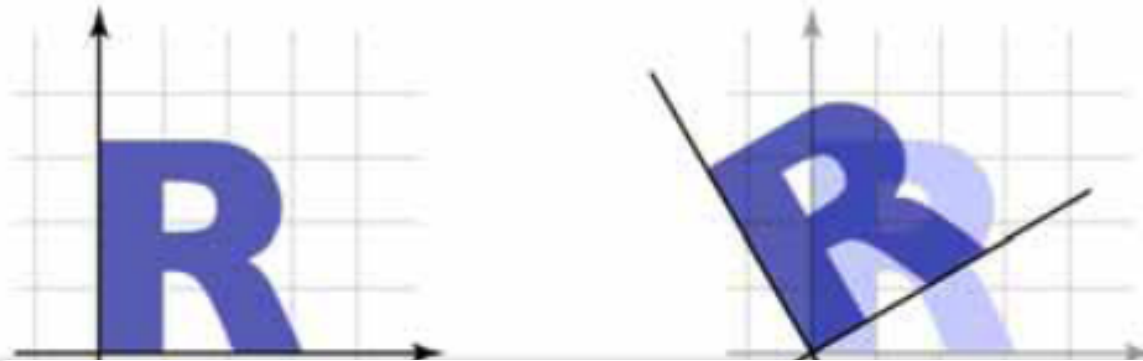


```
affine.setToScaling(sx,sy);
```

Matrix Transform Gallery

- Rotation:

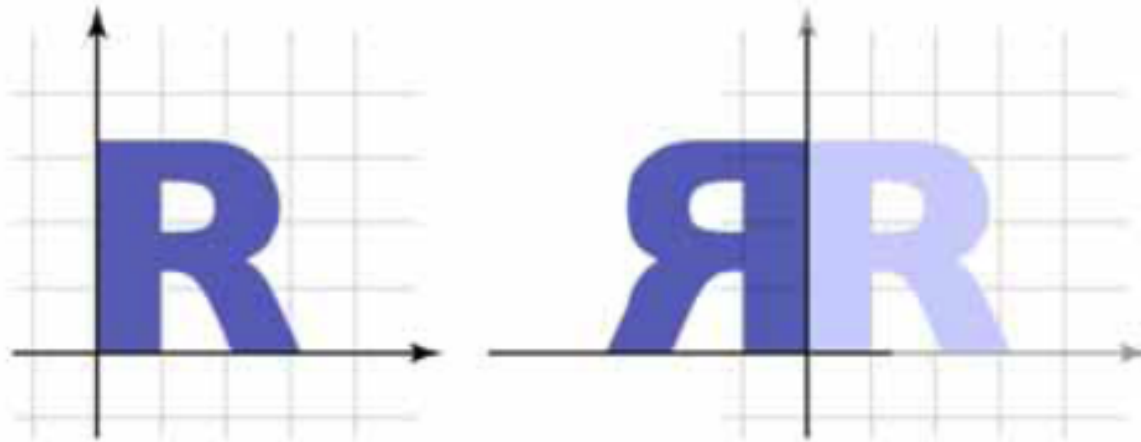
$$\begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} x \cos \theta - y \sin \theta \\ x \sin \theta + y \cos \theta \end{bmatrix}$$
$$\begin{bmatrix} 0.866 & -0.5 \\ 0.5 & 0.866 \end{bmatrix}$$



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



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);
```

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

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

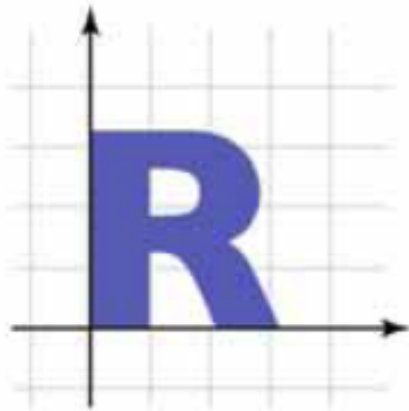
Affine Transforms Revisited

- **Affine**: Linear on homogenous coords
 - Equal to all transforms $T(\mathbf{v}) = M\mathbf{v} + \mathbf{p}$
 - 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

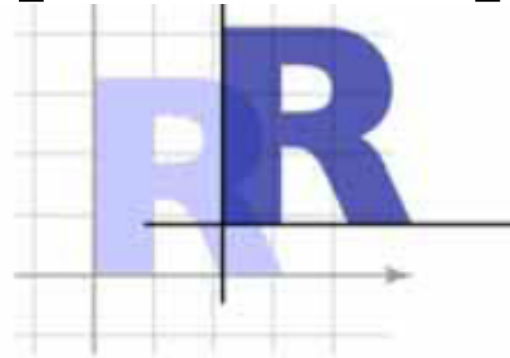
Affine Transform Gallery

- Translation:

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



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

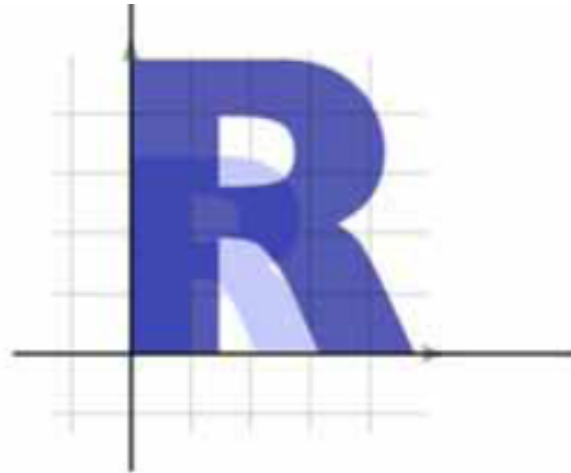
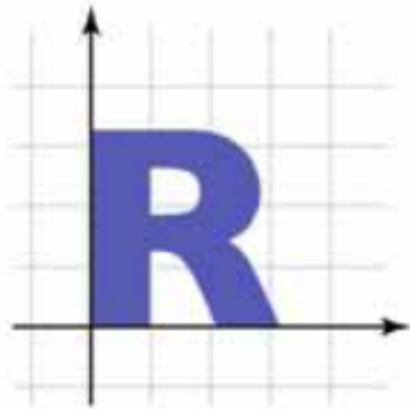


Affine Transform Gallery

- Uniform Scale:

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

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

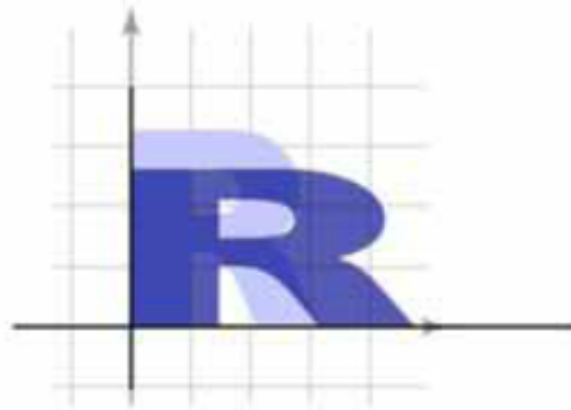
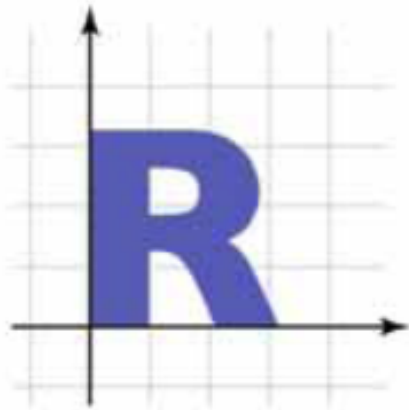


Affine Transform Gallery

- Nonuniform Scale:

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

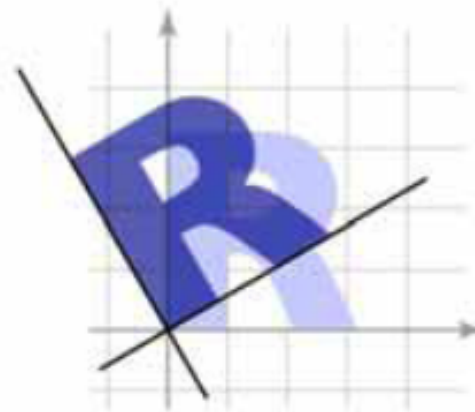
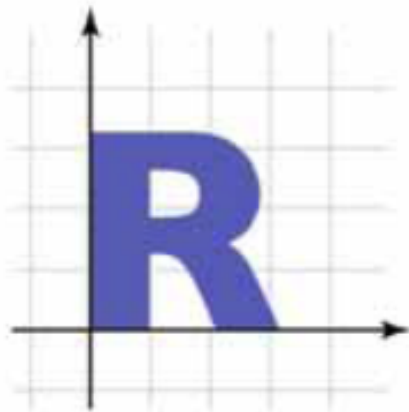
$$\begin{bmatrix} 1.5 & 0 & 0 \\ 0 & 0.8 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



Affine Transform Gallery

- Rotation:

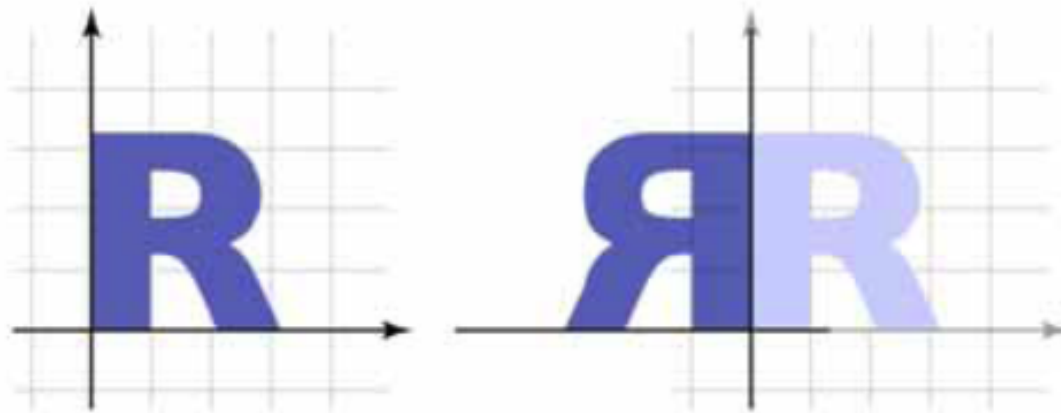
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Affine Transform Gallery

- Reflection:

- Special case of Scale
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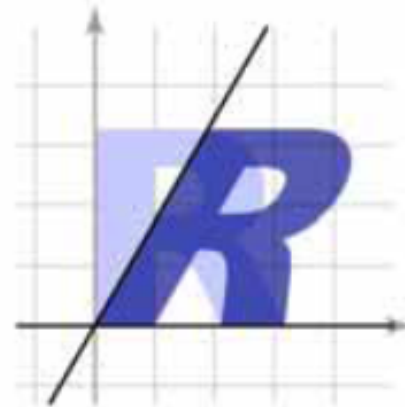
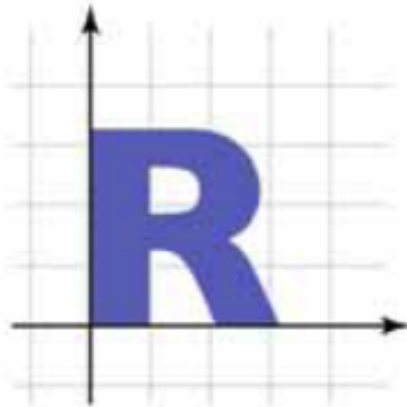


Affine Transform Gallery

- Shear:

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

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

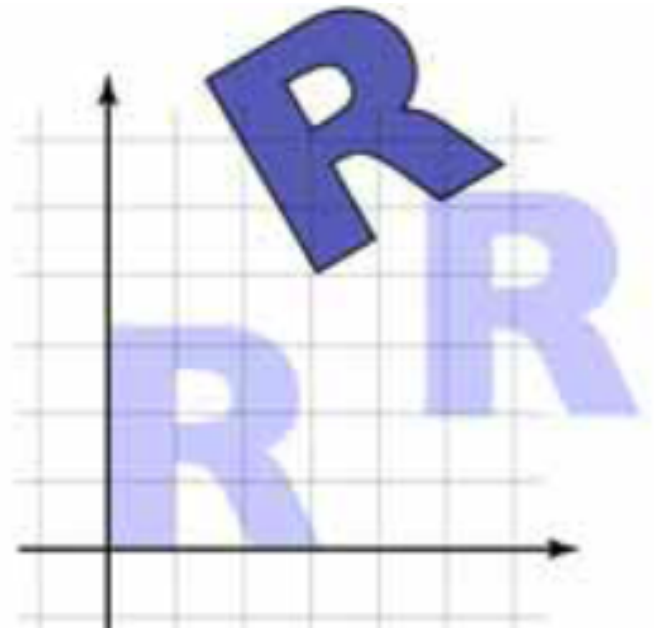


Compositing Transforms

- In general not commutative: order matters!



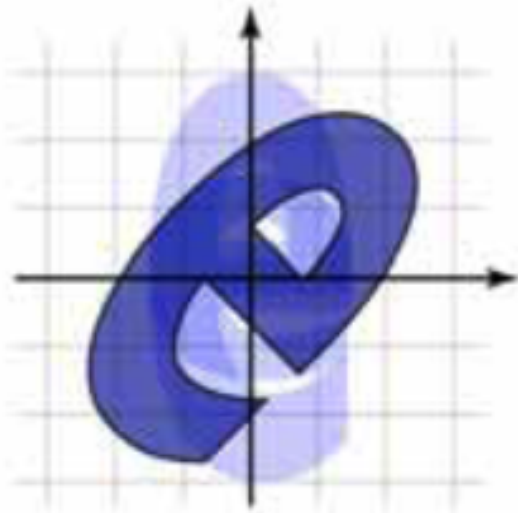
rotate, then translate



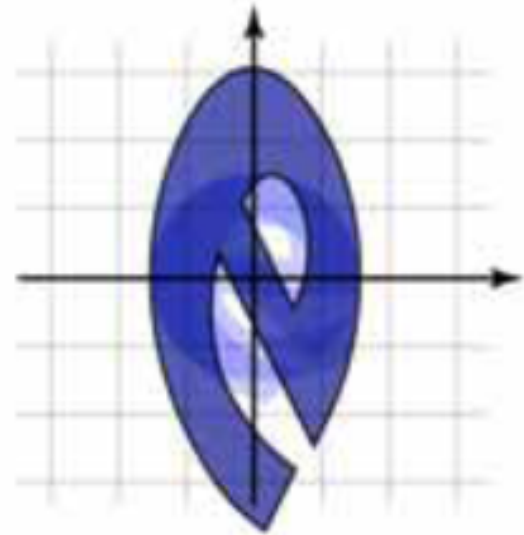
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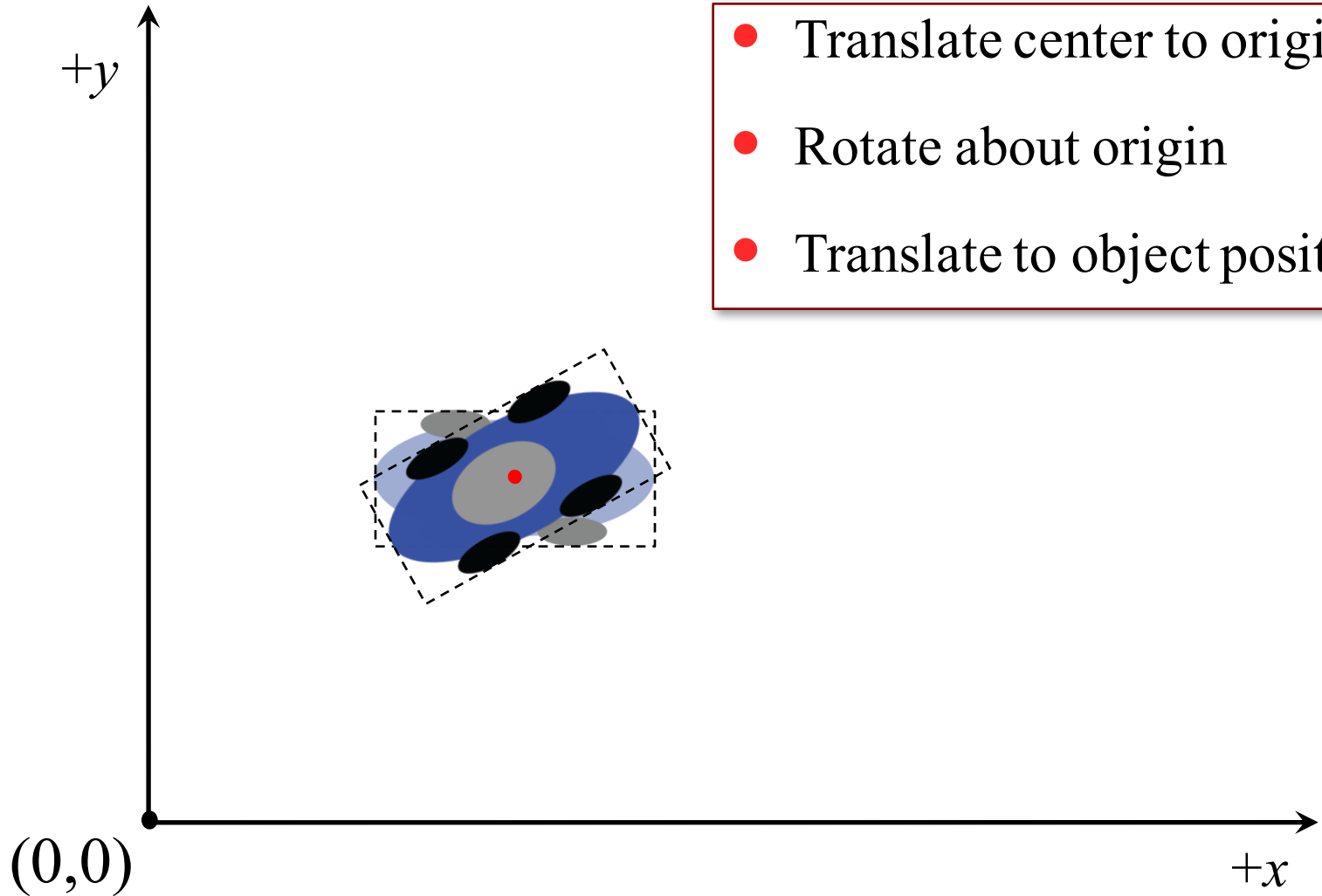


scale, then rotate



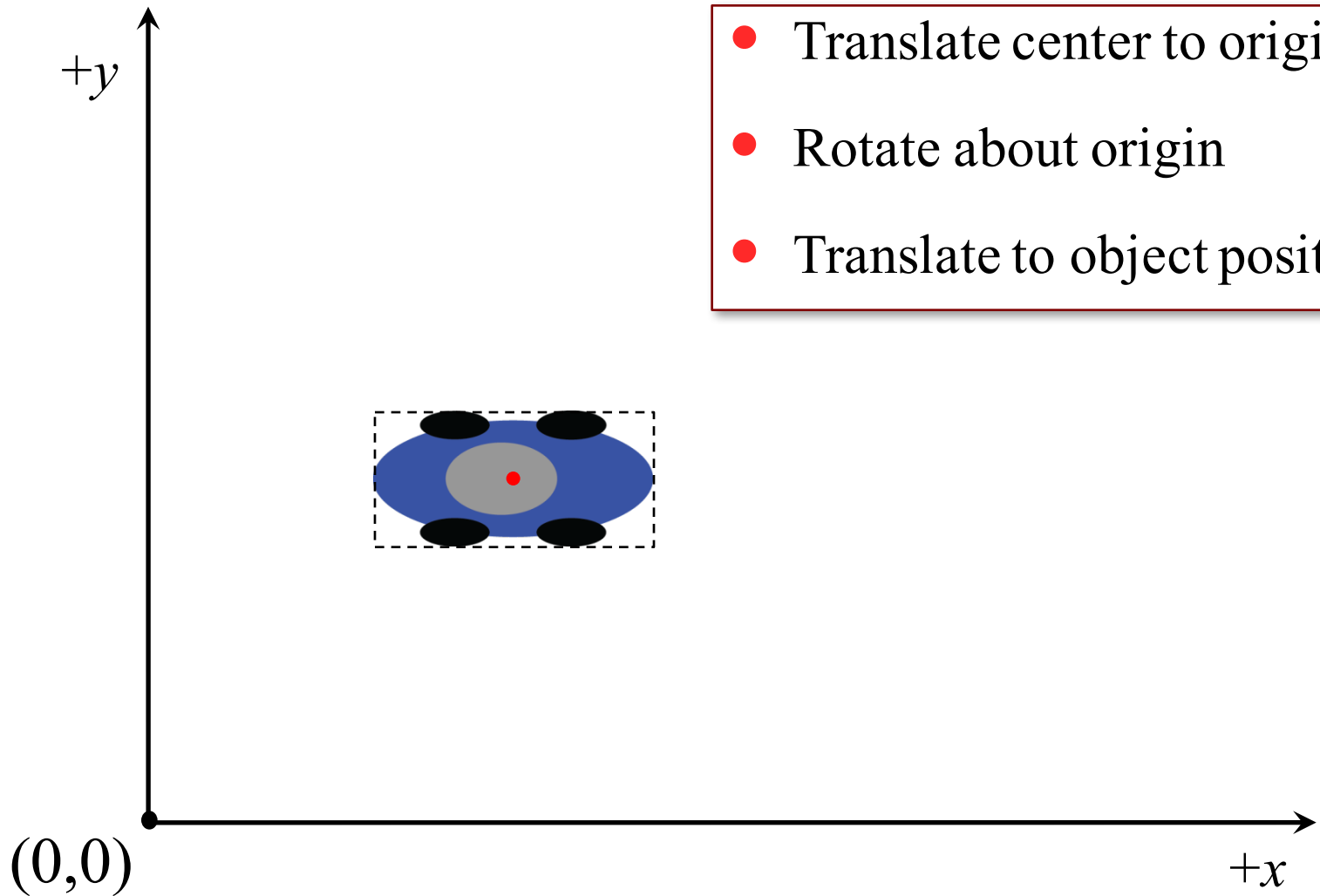
rotate, then scale

Rotating Object About Center



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

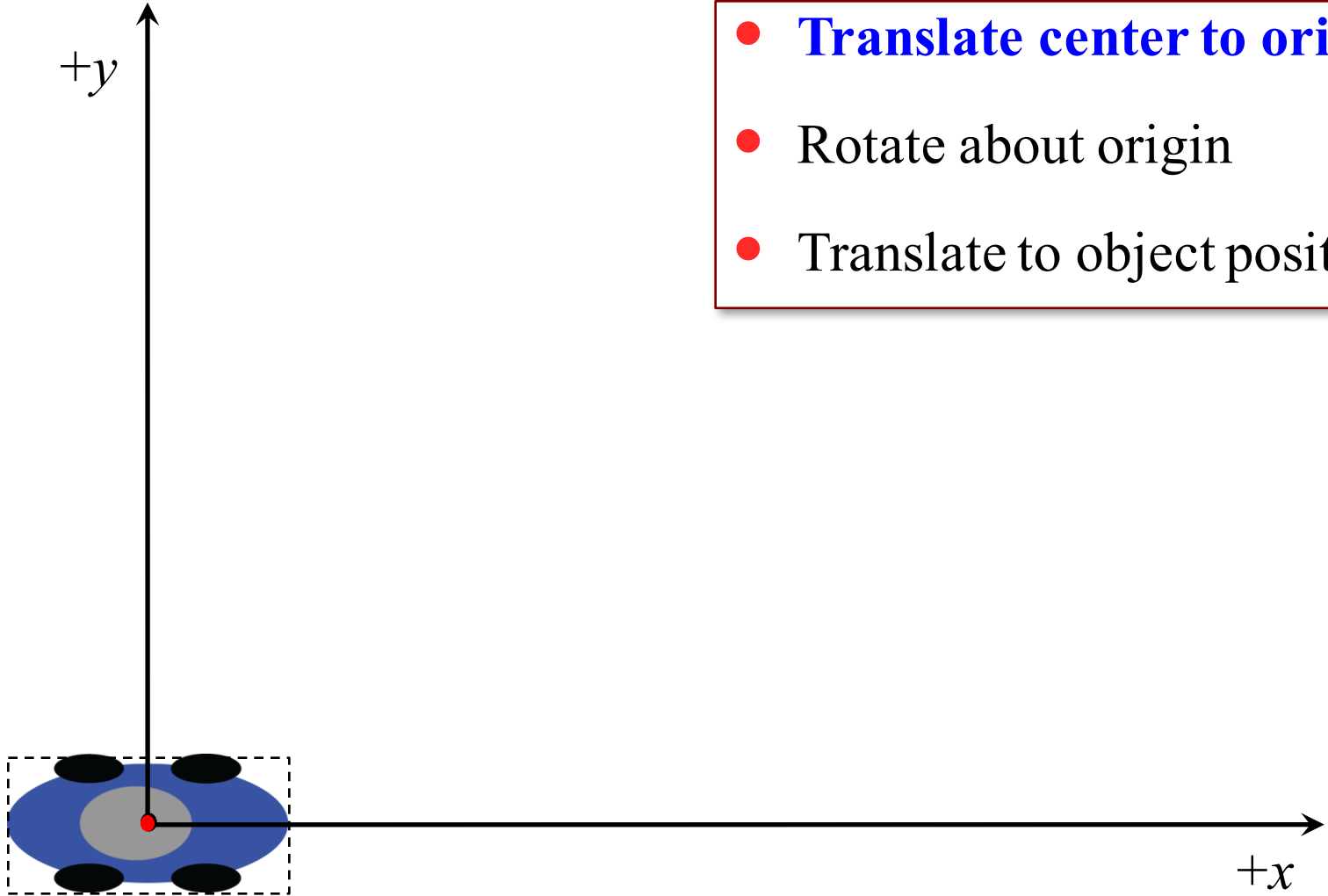
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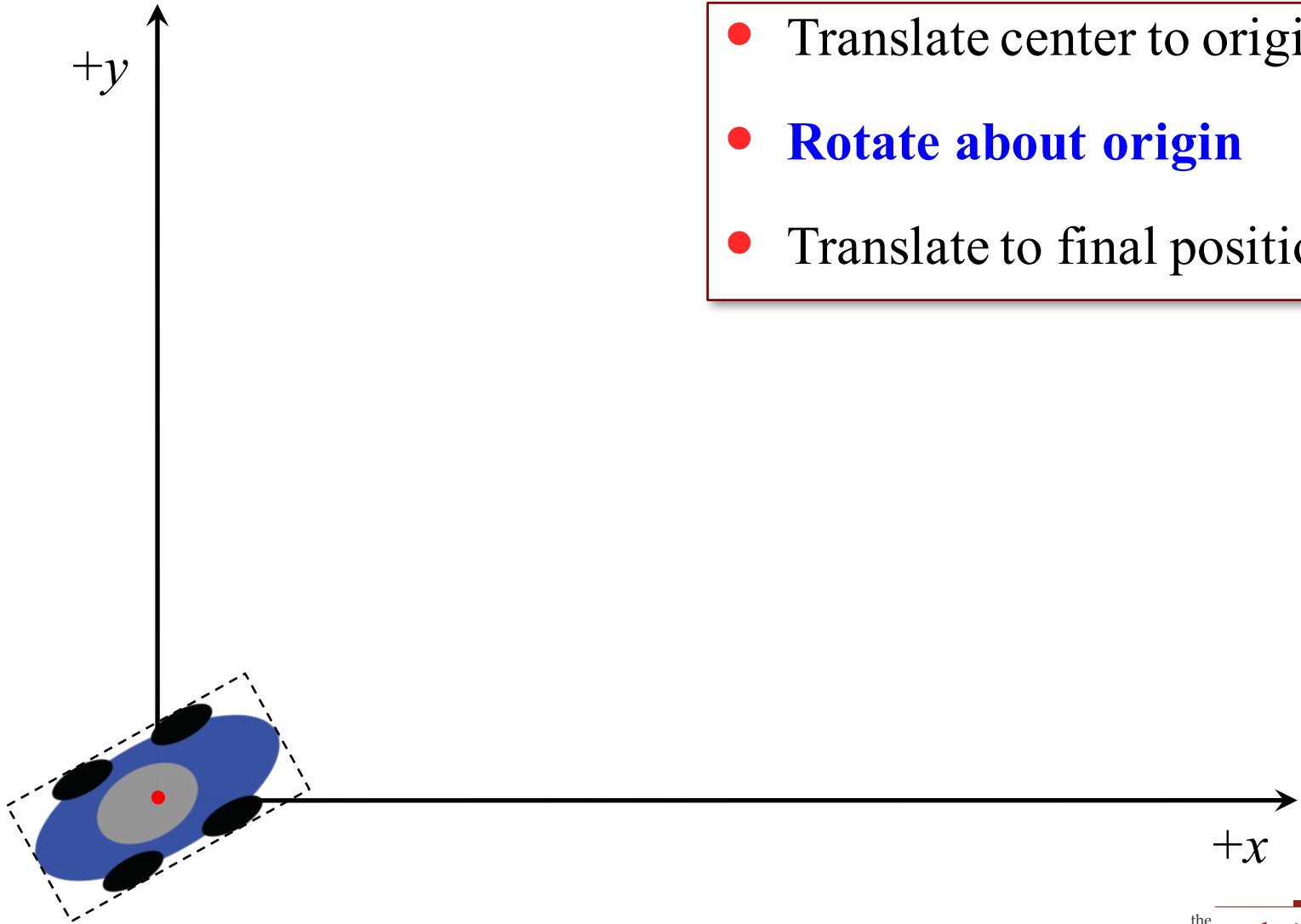
Rotating Object About Center

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

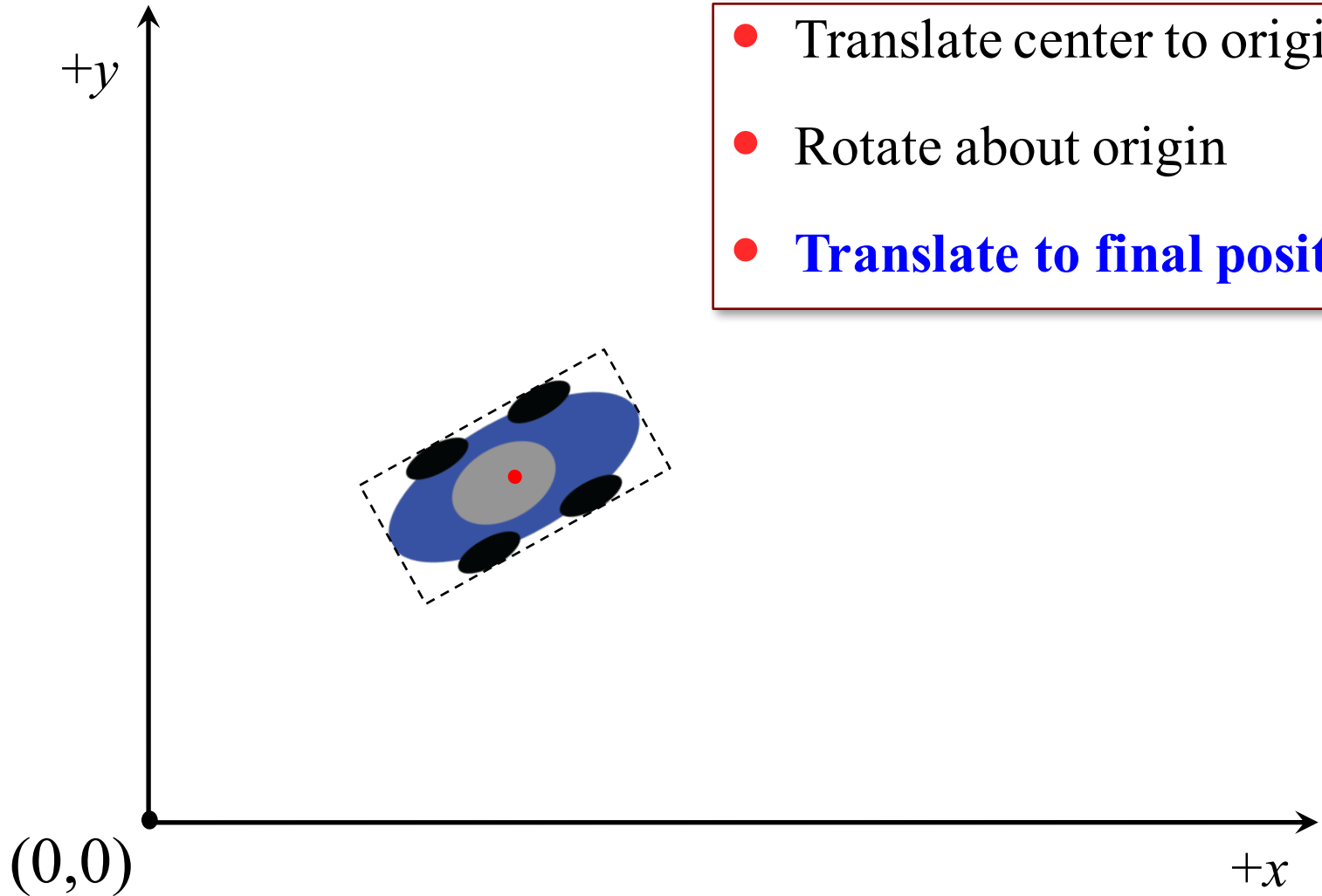


Rotating Object About Center

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



Rotating Object About Center



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

Transforms and Modular Animation

- Break asset into parts
 - Natural for joints/bodies
 - Animate each separately
- Cuts down on filmstrips
 - Most steps are transforms
 - A lot less for you to draw
 - Also better for physics
- Several tools to help you
 - **Example:** *Spriter, Spine*
 - Great for visualizing design



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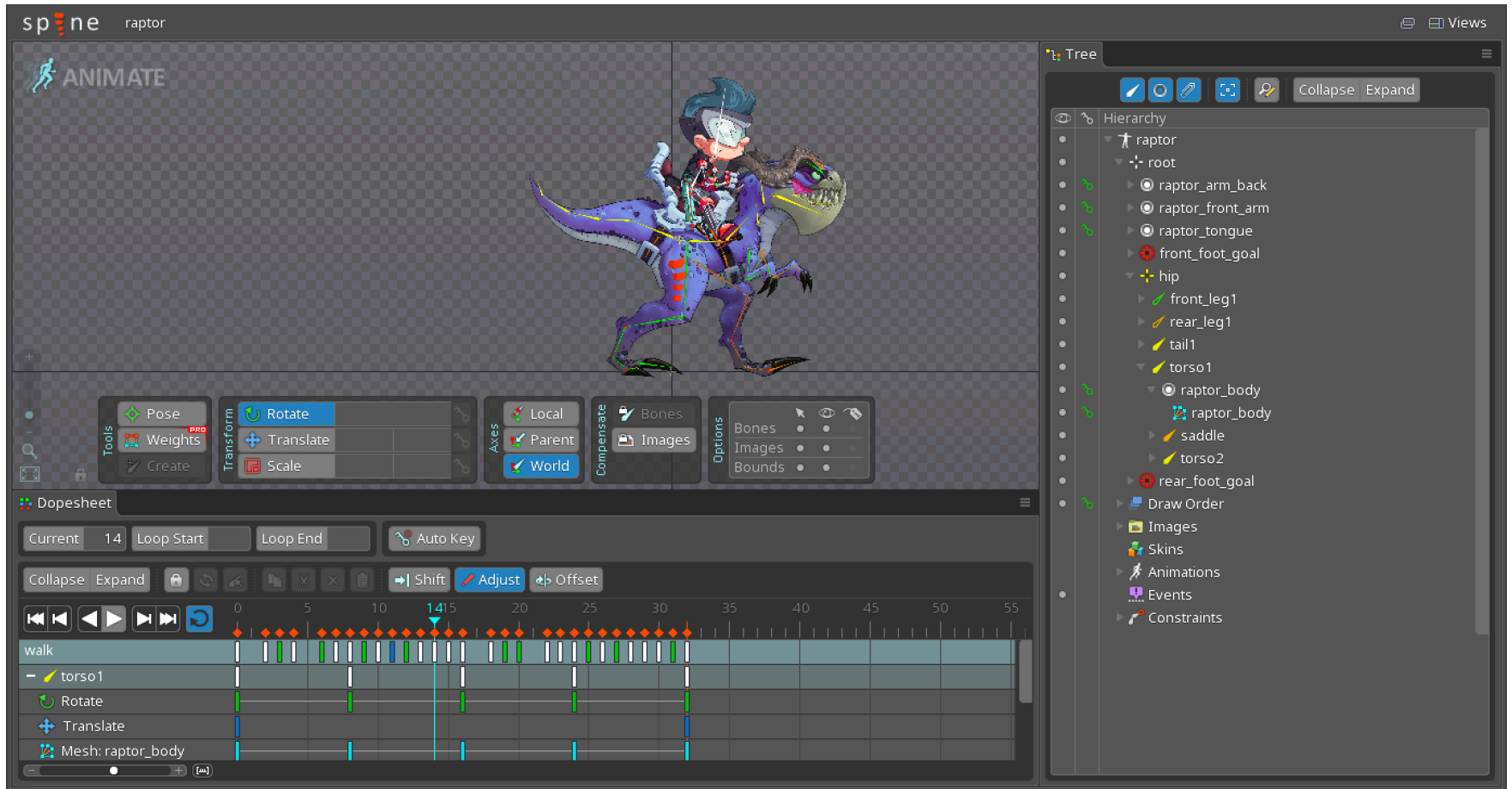


Transforms and Modular Animation

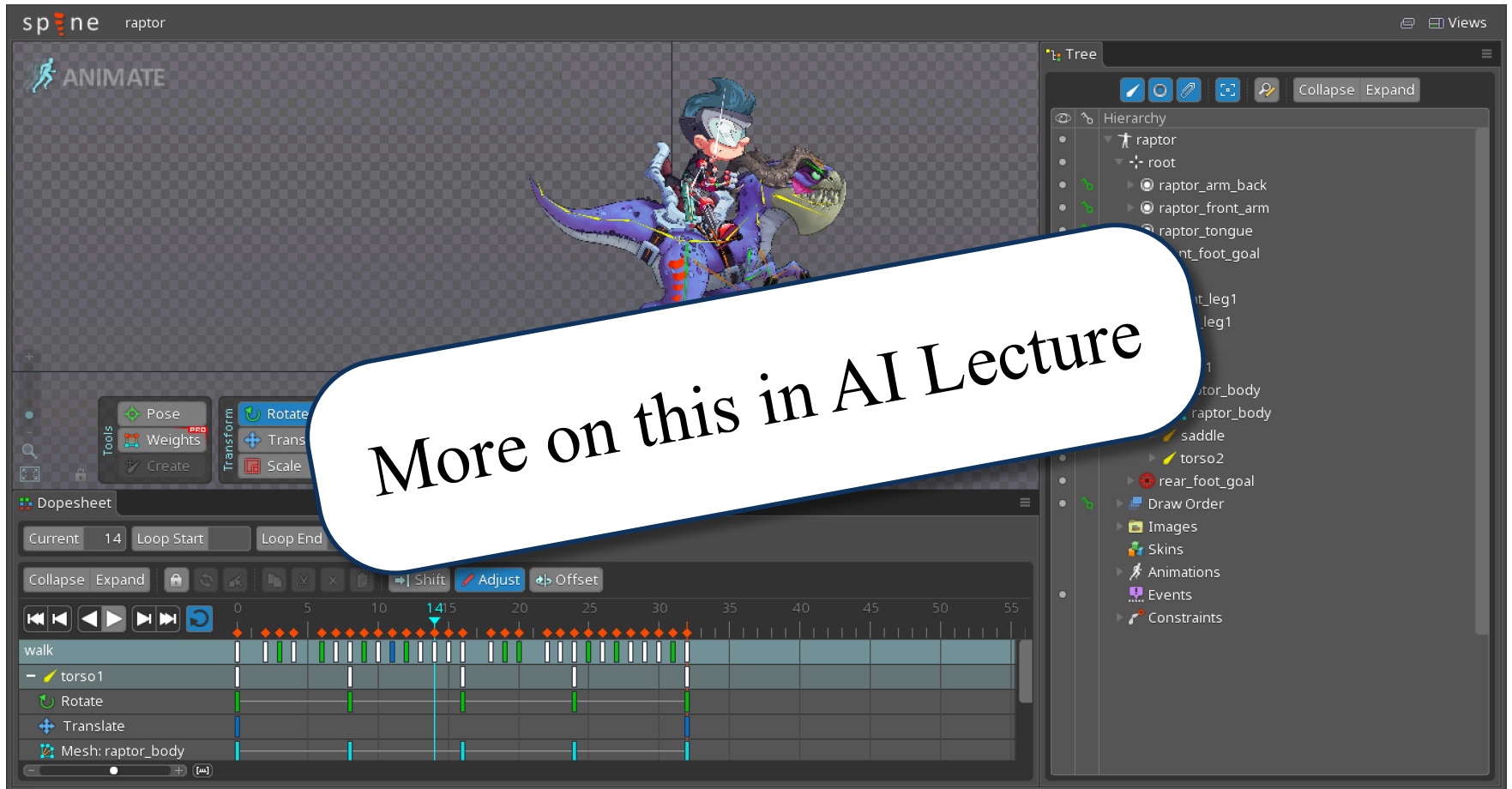
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 - Natural for joints/bodies
 - Animate each separately
- Cuts down on filmstrips
 - Most steps are transforms
 - A lot less for you to draw
 - Also better for physics
- Several tools to help you
 - **Example:** *Spriter, Spine*
 - Great for visualizing design



Spine Demo



Spine Demo

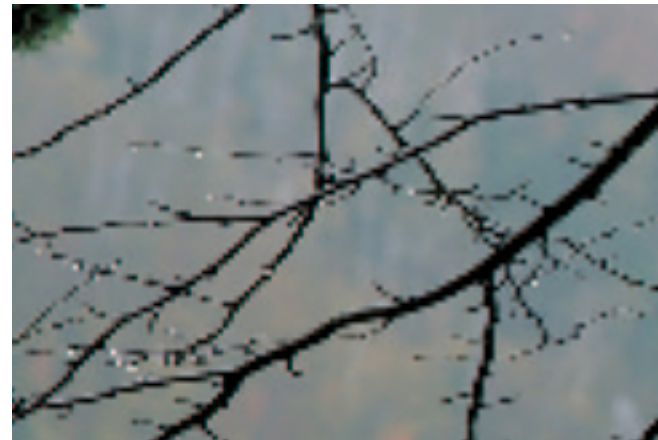


A Word About Scaling

- 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*

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”