the gamedesigninitiative at cornell university

Lecture 14

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

Animation is part of AI Lectures

Graphics Lectures

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

bare minimum to draw graphics

side-scroller vs. top down

necessary for lighting & shadows

Take Away for Today

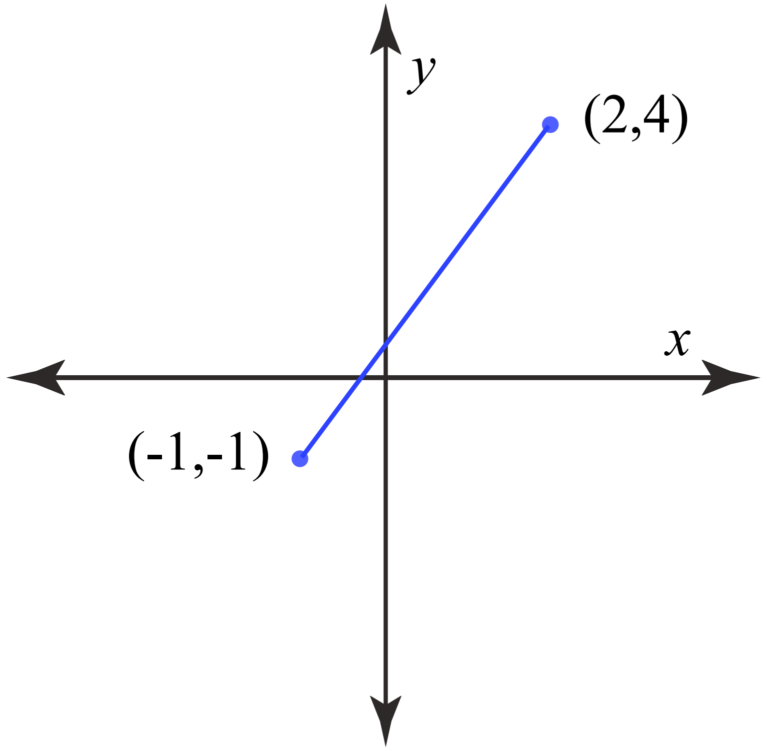
- **Coordinate Spaces** and drawing
  - What is screen space? Object space?
  - How do we use the two to draw objects?
  - Do we need any other spaces as well?
- **Drawing Transforms**
  - What is a drawing transform?
  - Describe the classic types of transforms.
  - List how to use transforms in a game.

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

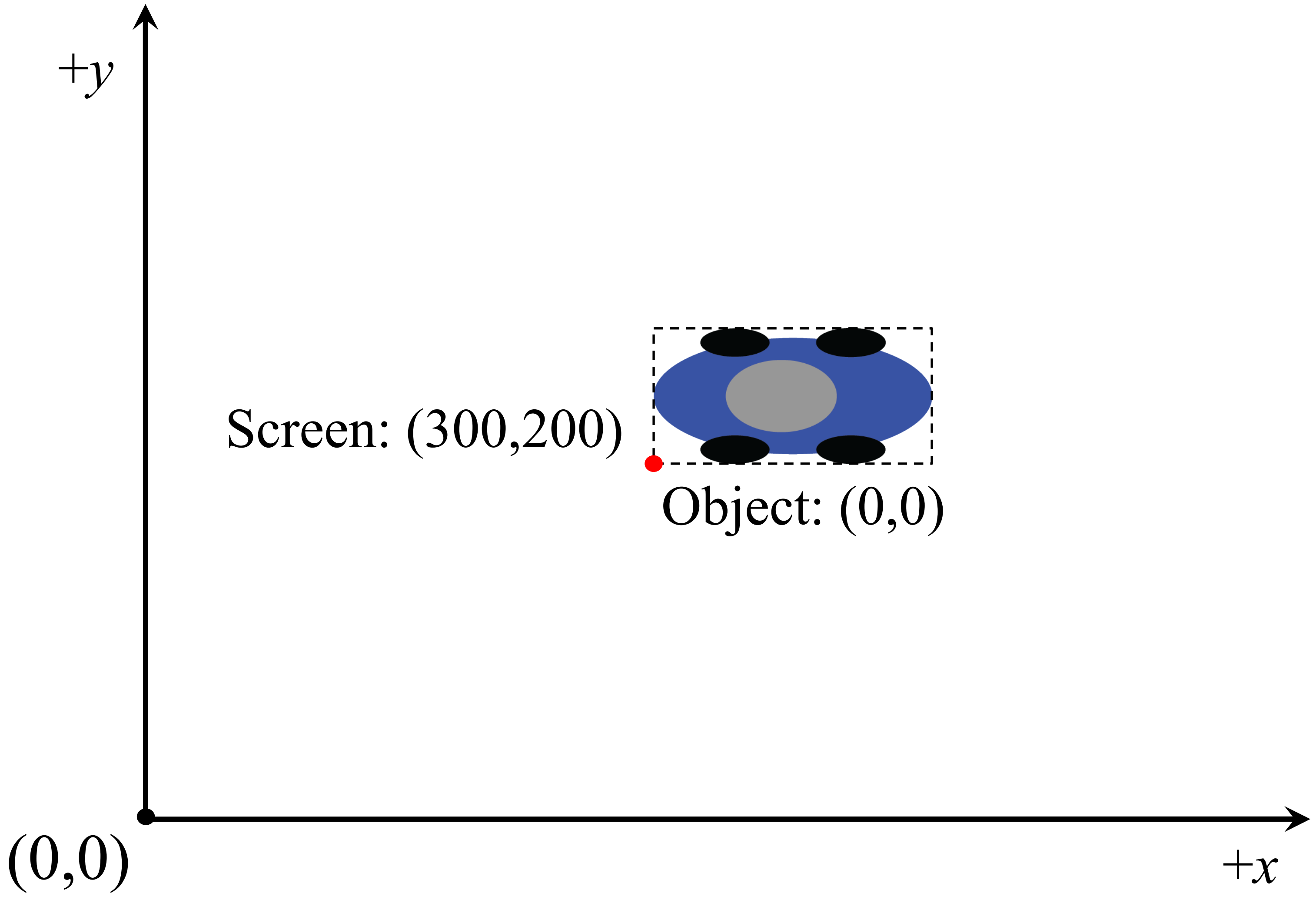
- Use **coordinate systems**
  - Each pixel has a coordinate
  - Draw something at a pixel by
    - Specifying what to draw
    - Specifying where to draw
- Do we draw each pixel?
  - Use a drawing API
  - Given an image; does work
  - What LibGDX gives us



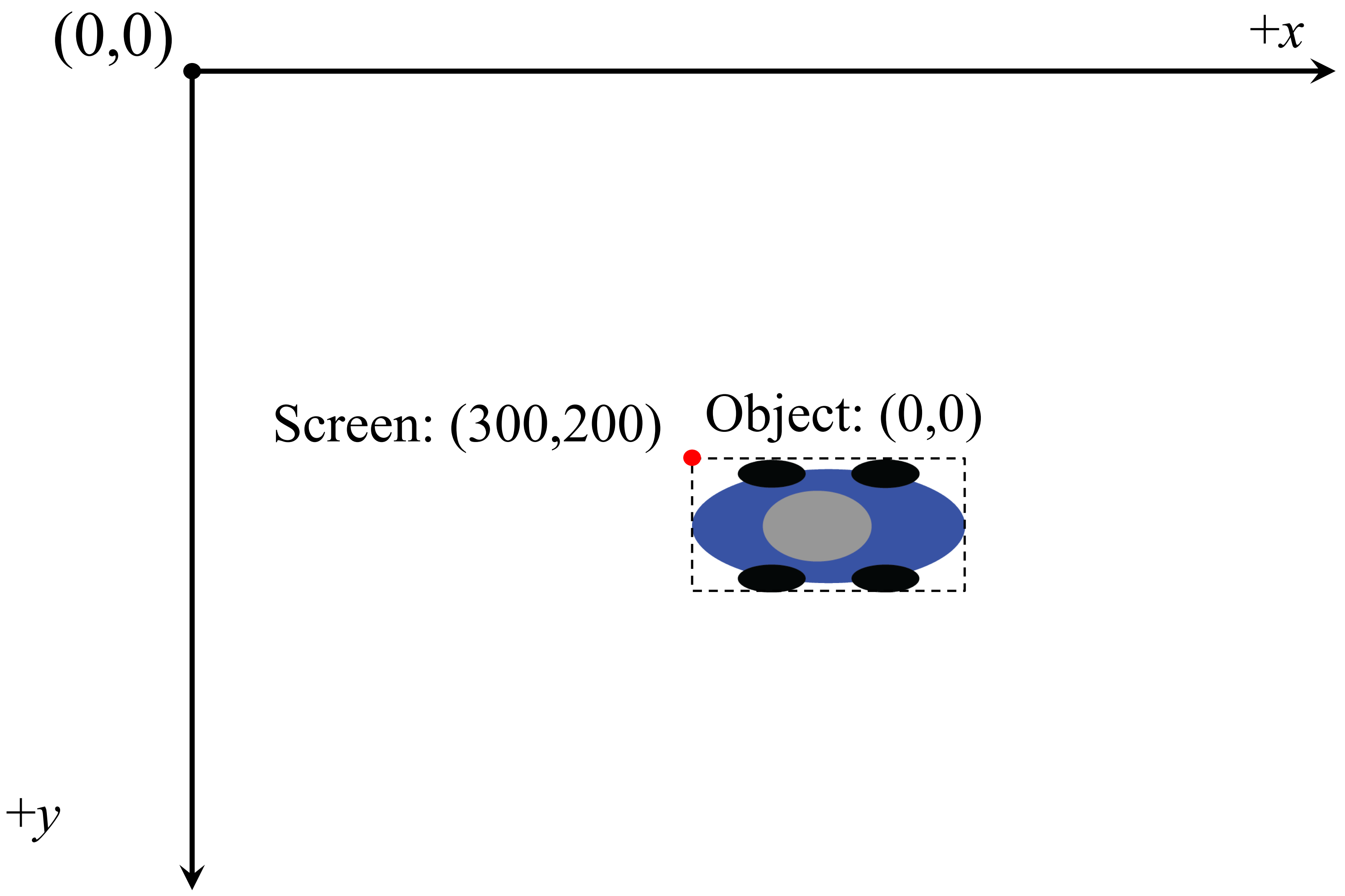
Sprite Coordinate Systems

- **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

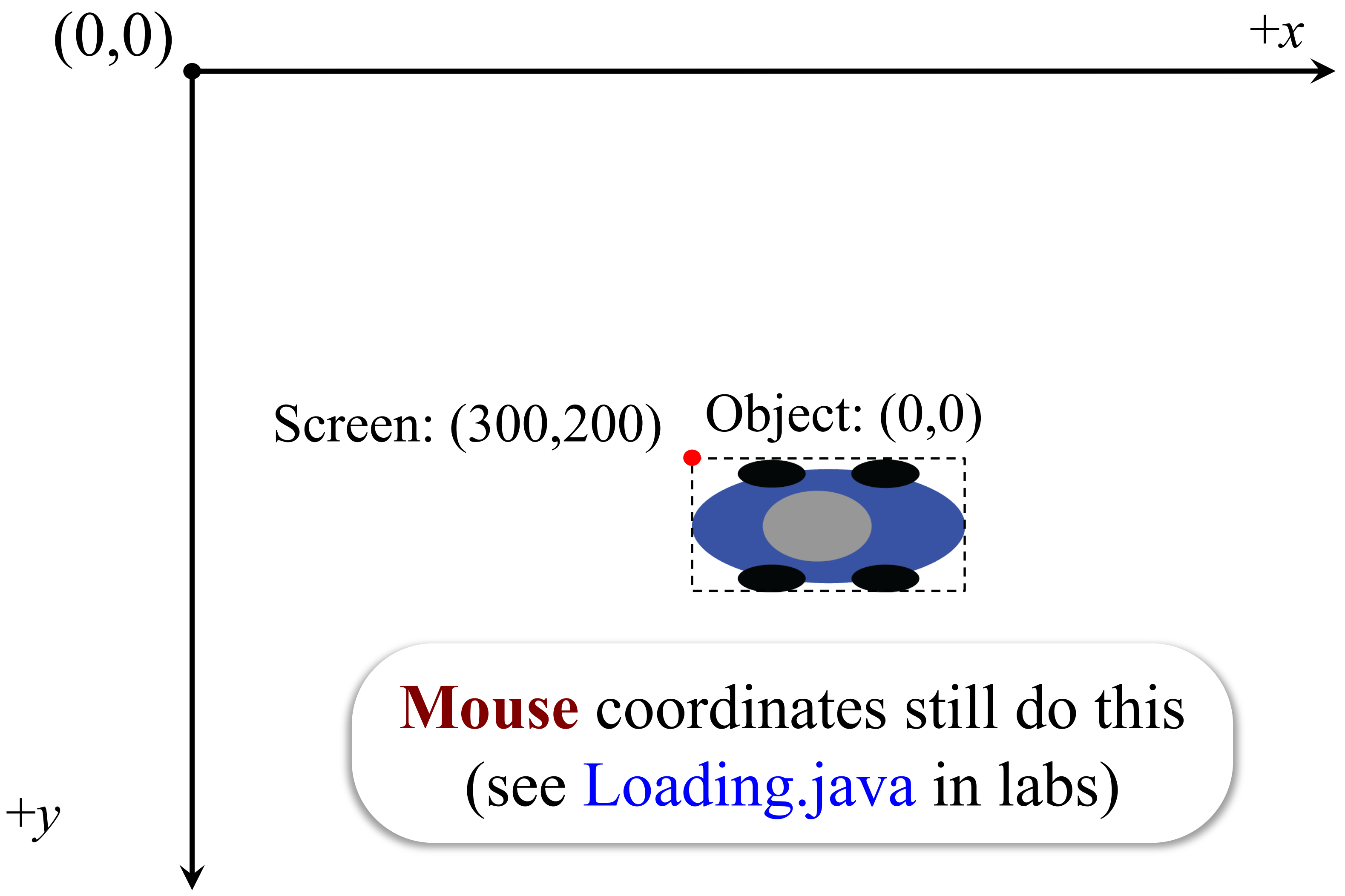
Sprite Coordinate Systems



Historical Coordinate Systems



Historical Coordinate Systems

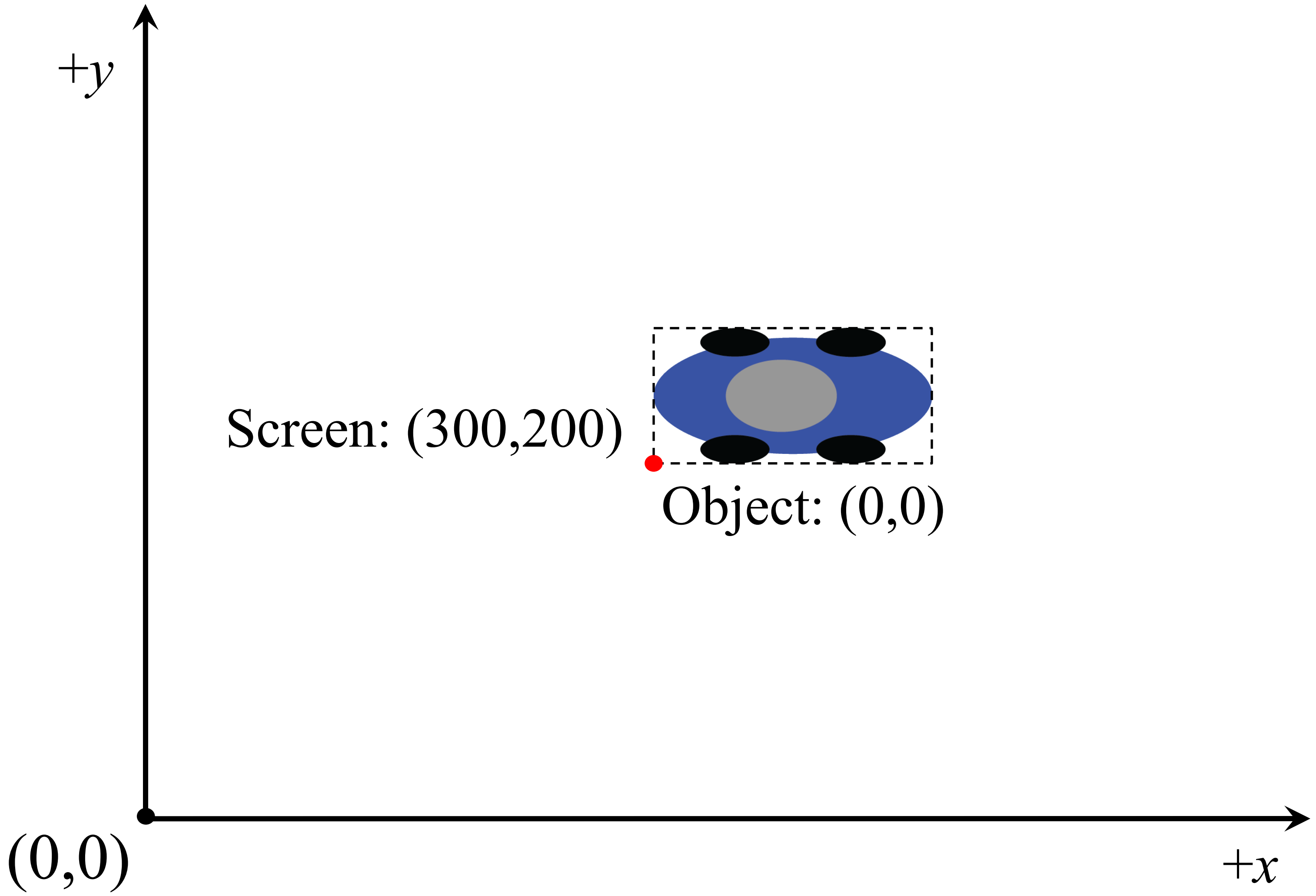


Mouse coordinates still do this
(see Loading.java in labs)

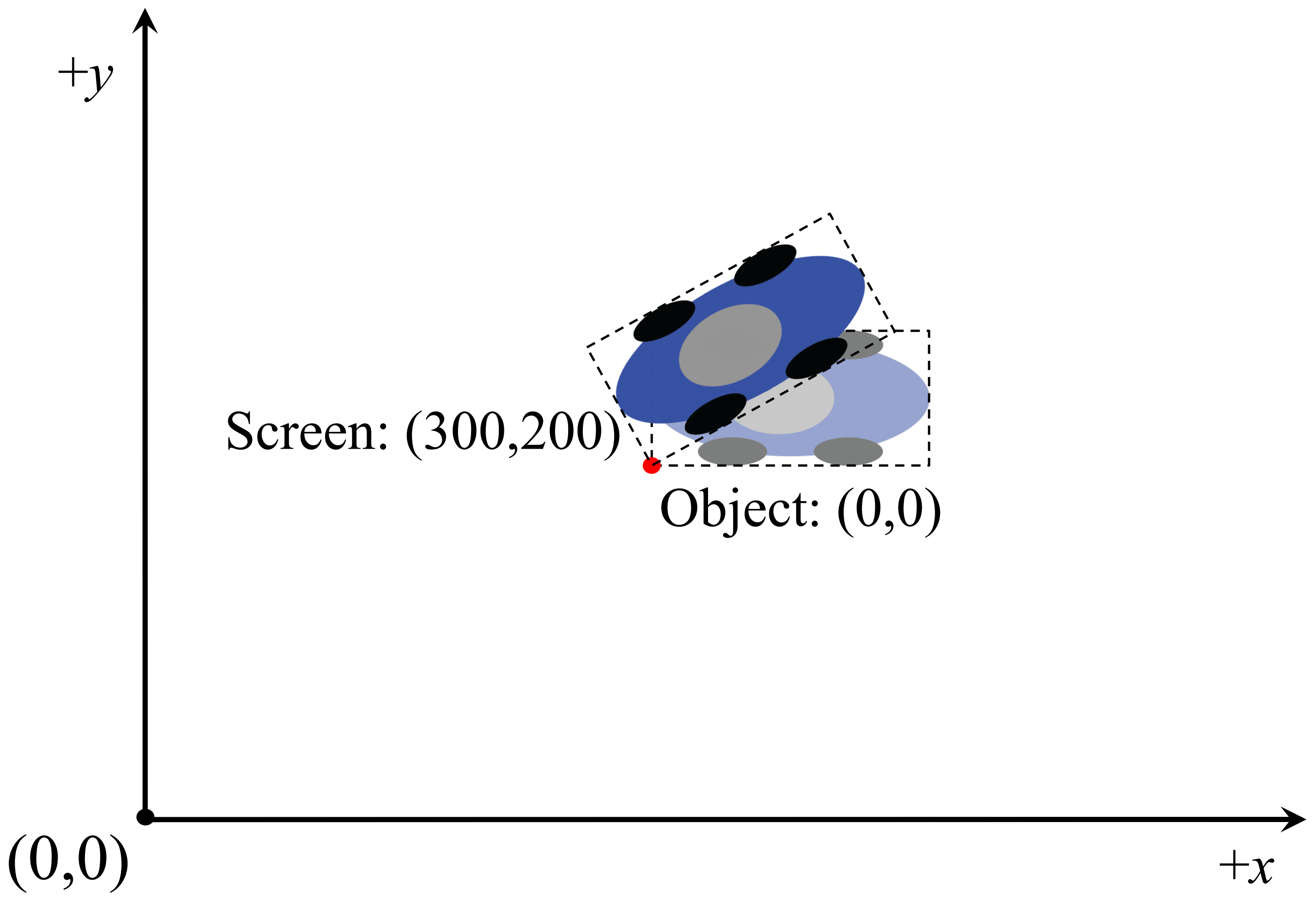
Drawing Sprites

- **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

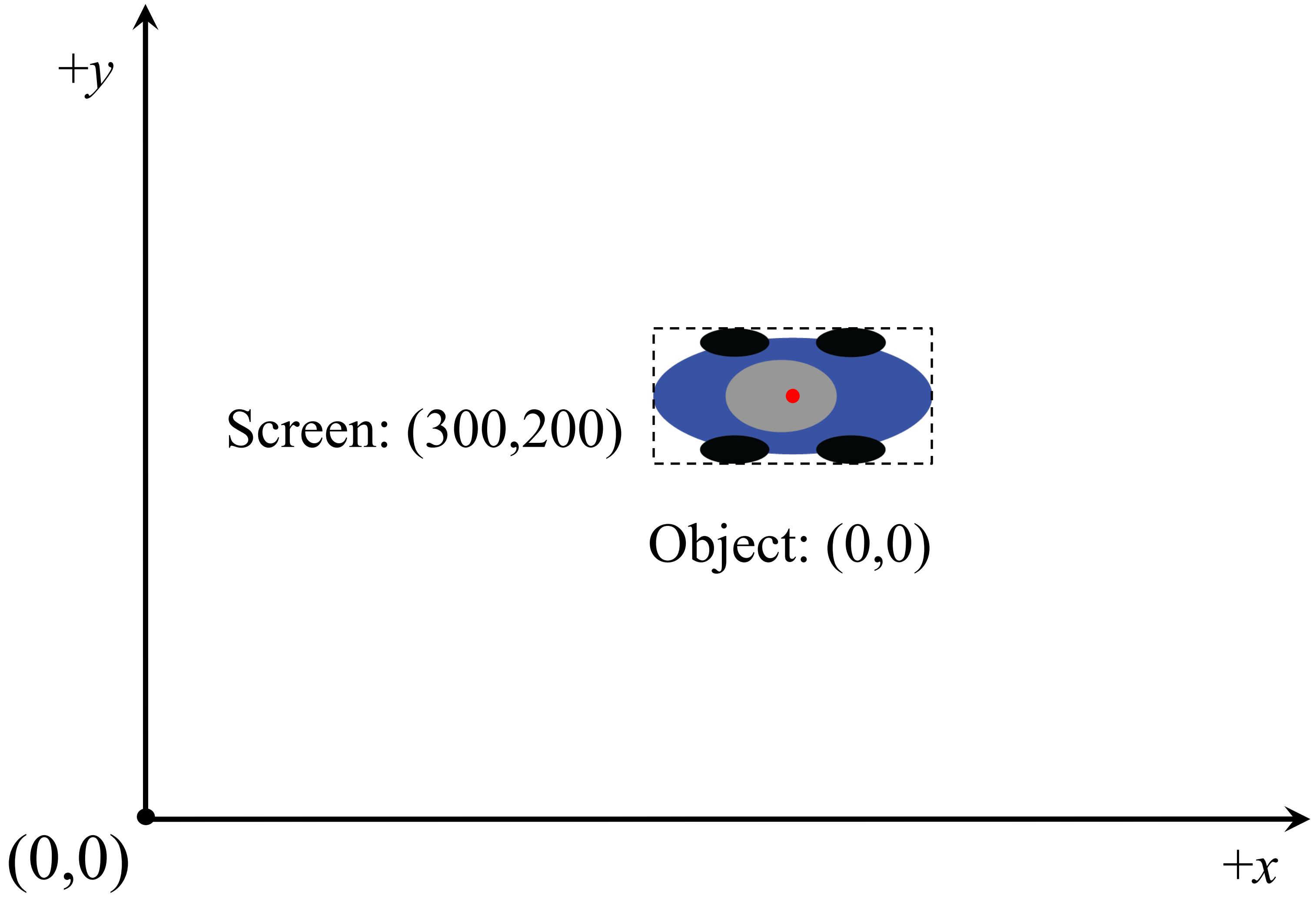
Sprite Coordinate Systems



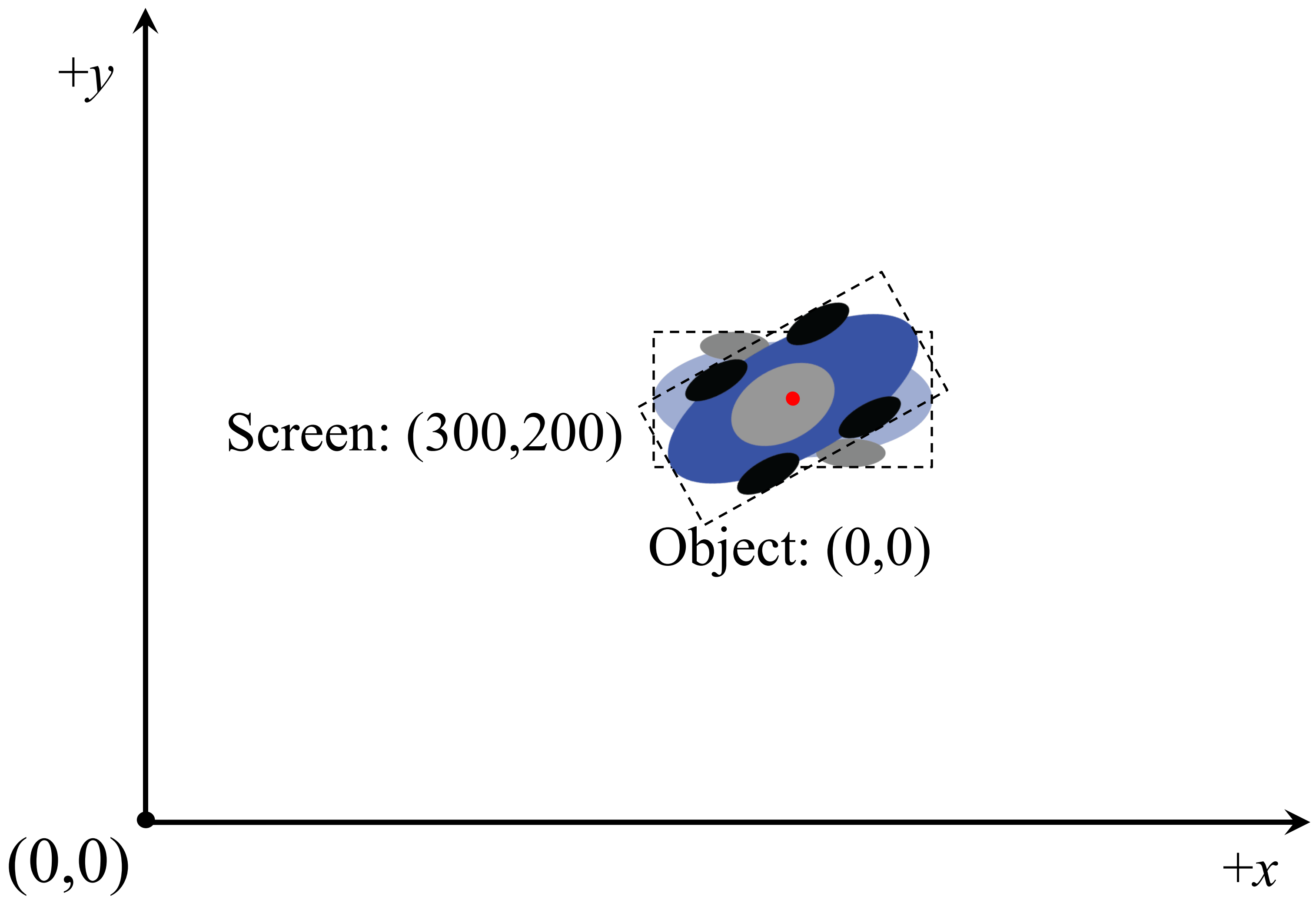
Sprite Coordinate Systems



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();
    …
}
```

$\underbrace{\texttt{pos.x, pos.y}}_{\text{screen coordinates}}$

2D Transforms

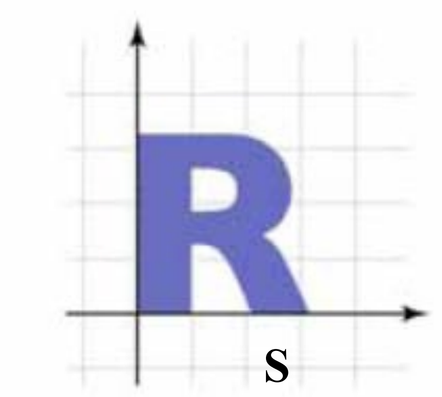
- A function $T : \mathbb{R}^2 \rightarrow \mathbb{R}^2$
  - "Moves" one set of points to another set of points
  - Transforms one "coordinate system" to another
  - The new coordinate system is the distortion
- **Idea**: Draw on paper and then "distort" it
  - **Examples**: Stretching, rotating, reflecting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

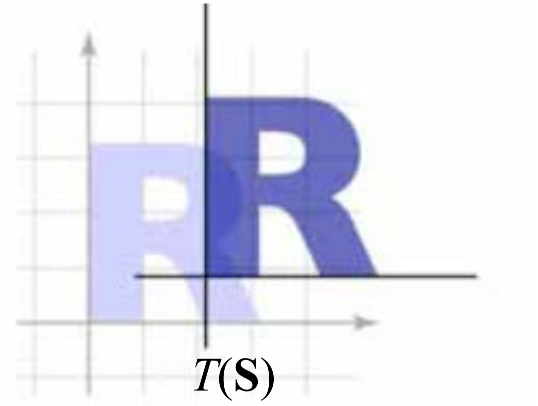
The “Drawing Transform”

- T : object coords → 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 **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**

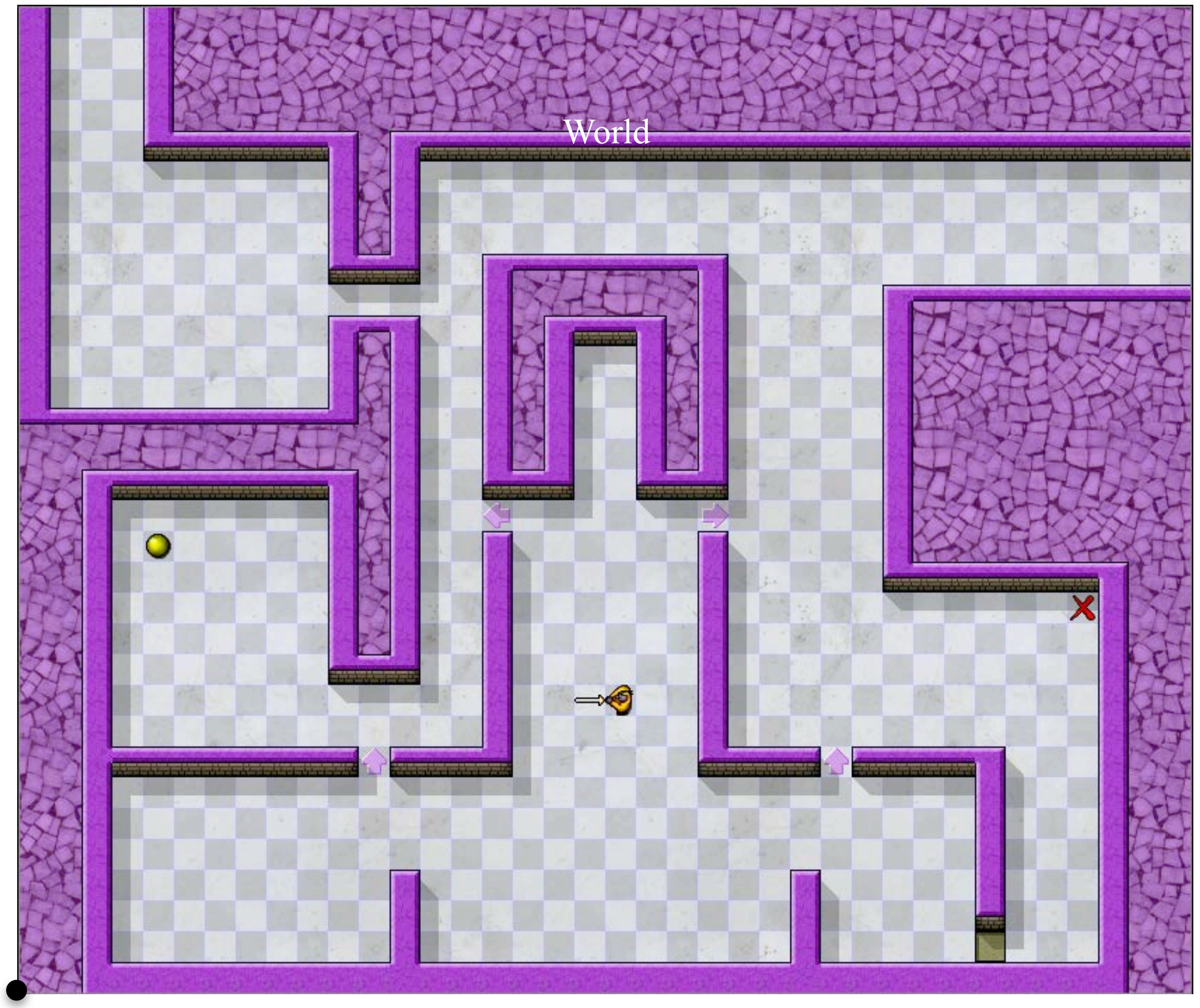




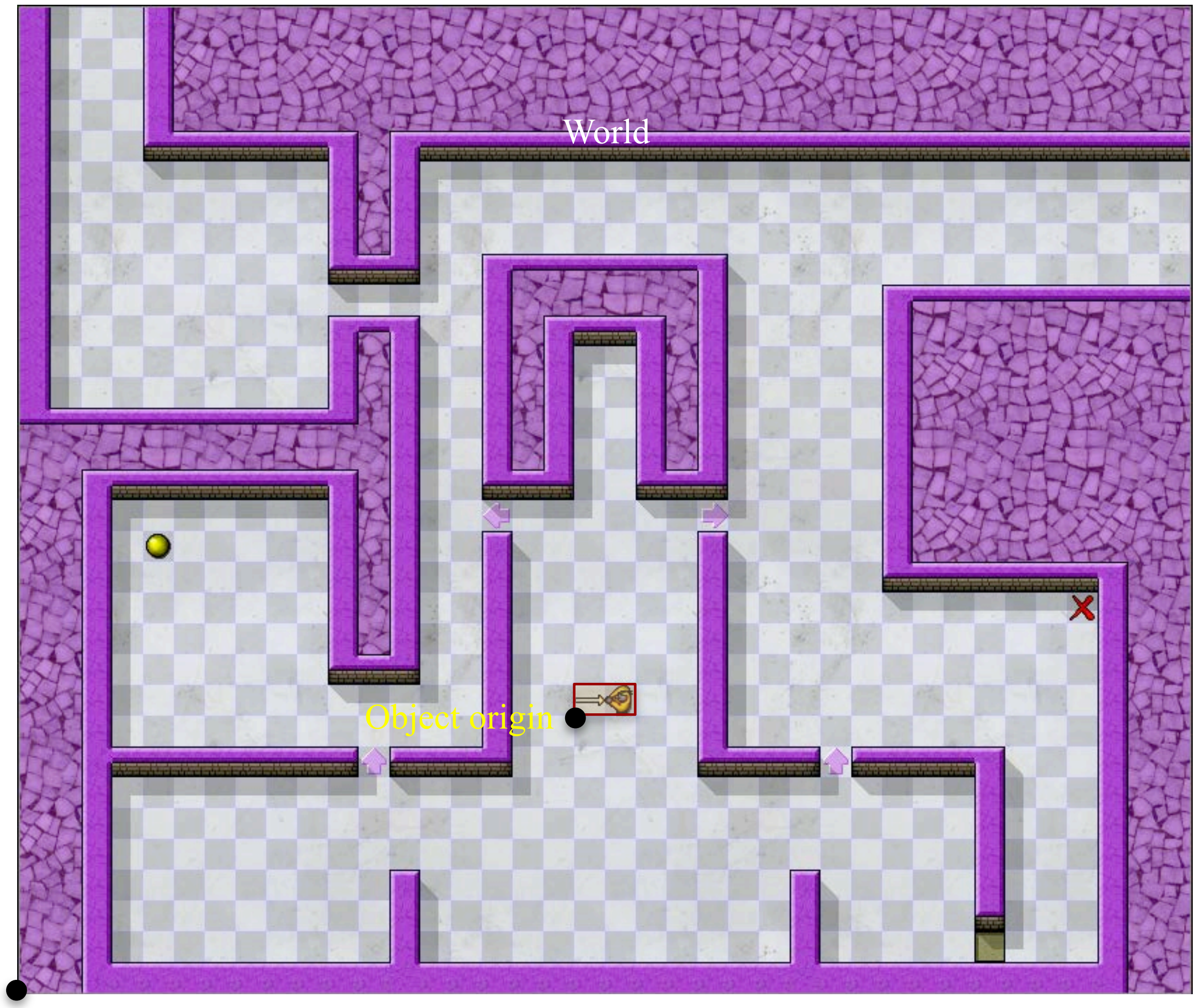
Composing Transforms

- **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

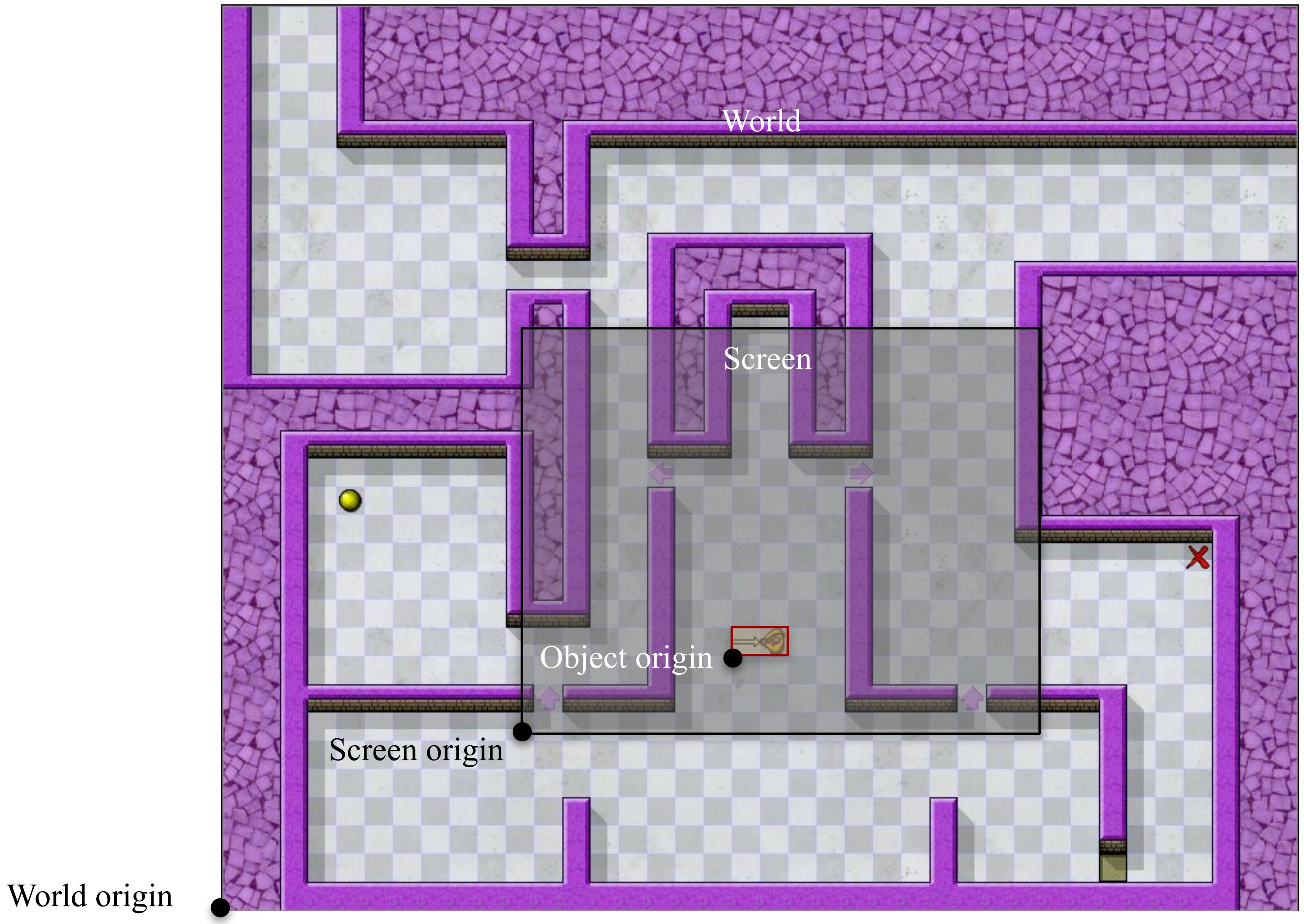
Application: Scrolling



Application: Scrolling



Application: Scrolling



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 $\mathbf{p}\text{-}\mathbf{q}$
  - $S(\mathbf{v}) = \mathbf{v}\text{-}\mathbf{q}$ 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 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)

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
  - 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

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());



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

Translate origin to position in world.

why did they do this???

Positioning in LibGDX

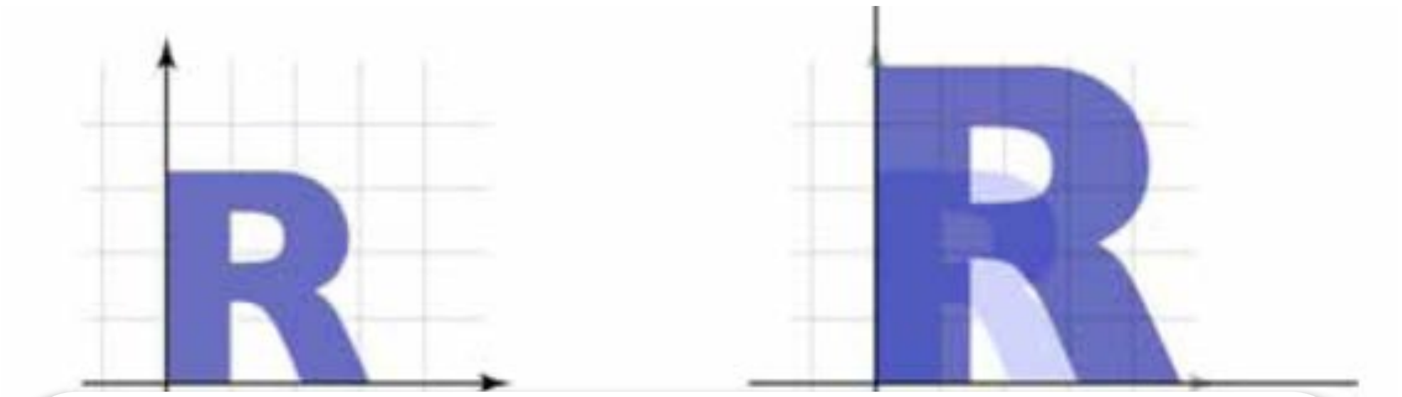
```
public void draw(float dt) {
    Affine2 oTran = new Affine2();
    oTran.setToTranslation(object.getPosition());
    Affine2 wtran = new Affine2();
    Vector2 wPos = viewWindow.getPosition();
    wTran.setToTranslation(-wPos.x,-wPos.y);
    oTran.mul(wTran);
    spriteBatch.begin();
        spriteBatch.draw(image,width,height,oTran);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

scrolling support

Transform Gallery

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

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



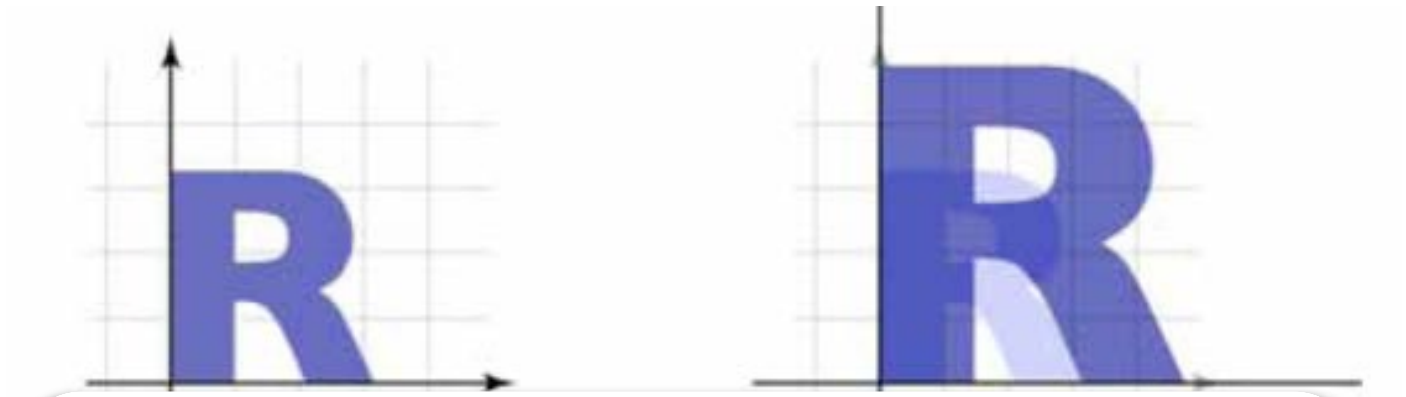
```
affine.setToScaling(s,s);
```

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

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

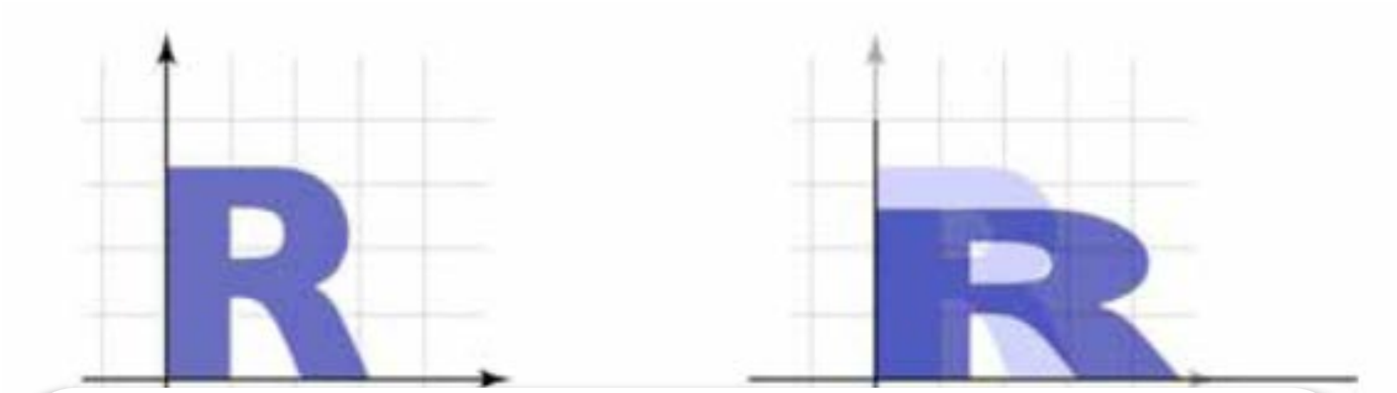


```
affine.setToScaling(s,s);
```

Matrix Transform Gallery

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

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



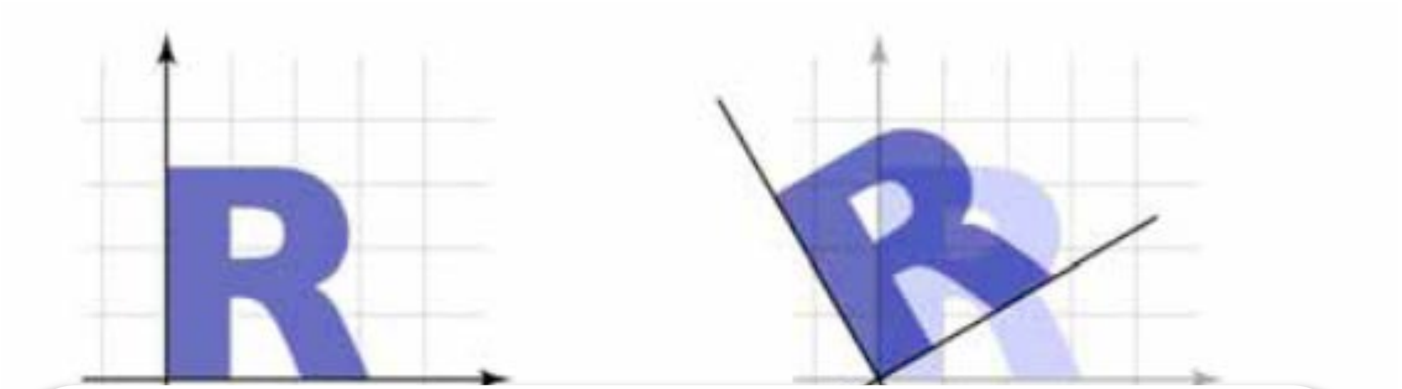
```
affine.setToScaling(sx,sy);
```

Matrix Transform Gallery

- Rotation:

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

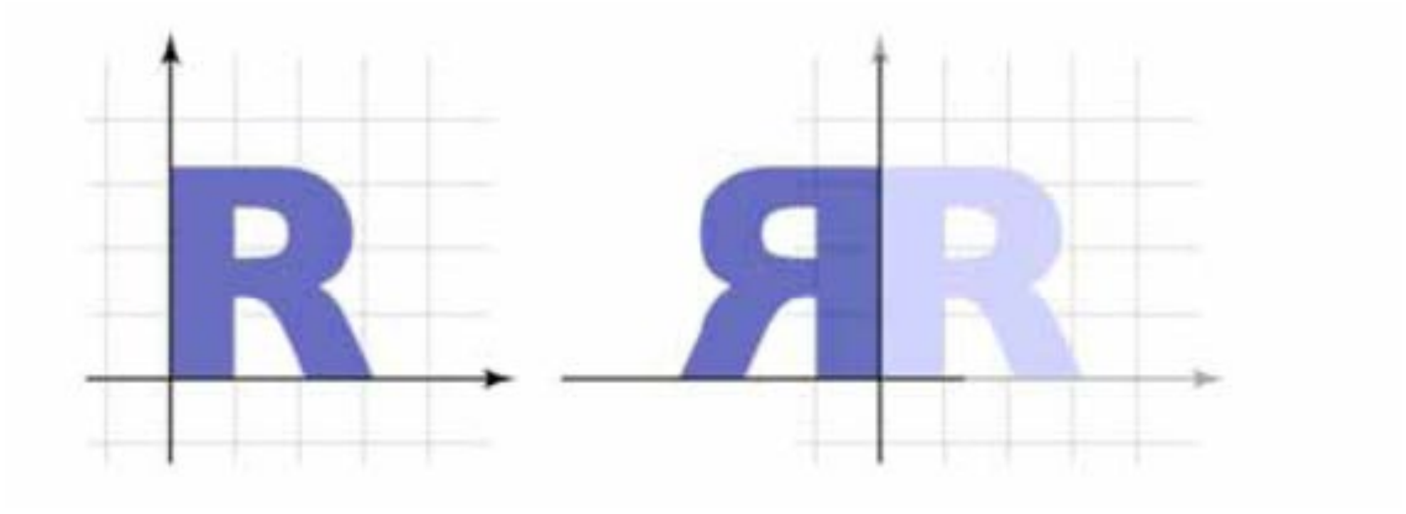
$$\begin{bmatrix} 0.866 & -0.5 \\ 0.5 & 0.866 \end{bmatrix}$$



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

Matrix Transform Gallery

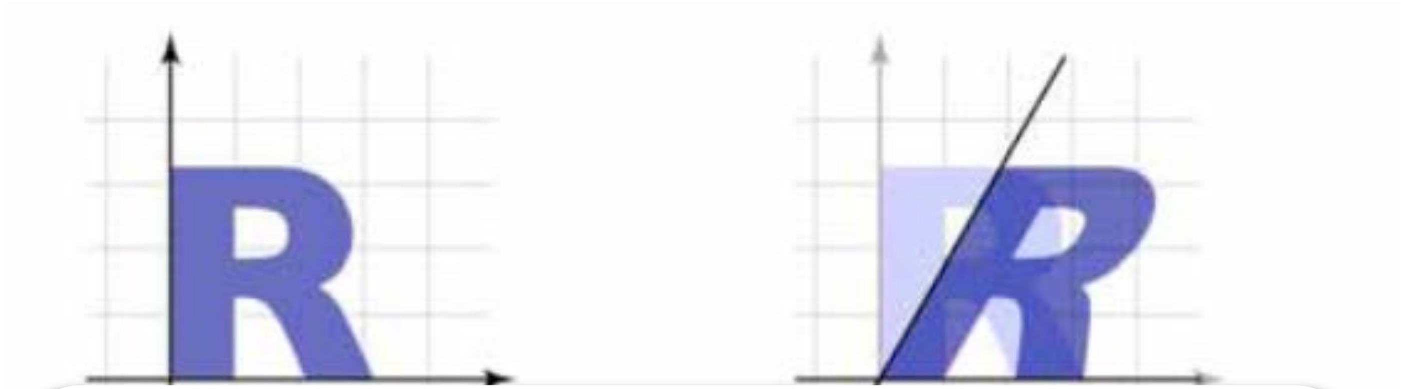
- Reflection: $$\begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} -x \\ y \end{bmatrix}$$
  - View as special case of Scale $$\begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}$$



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

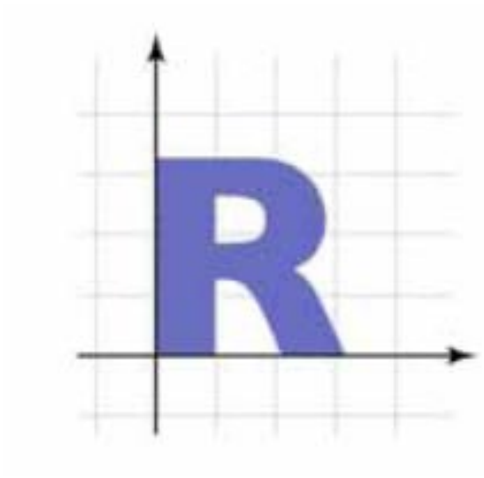
- **Affine**: Linear on homogenous coords
  - Equal to all transforms $T(\mathbf{v}) = \mathrm{M}\mathbf{v}+\mathbf{p}$
  - Treat everything as matrix multiplication
- Why does this work?
  - Area of mathematics called projective geometry
  - Far beyond the scope of this class
- LibGDX hides all the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

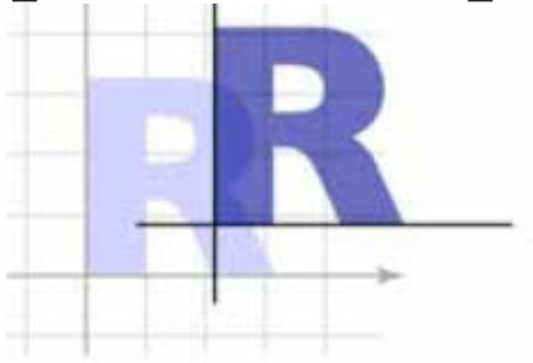
Affine Transform Gallery

- Translation:

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

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

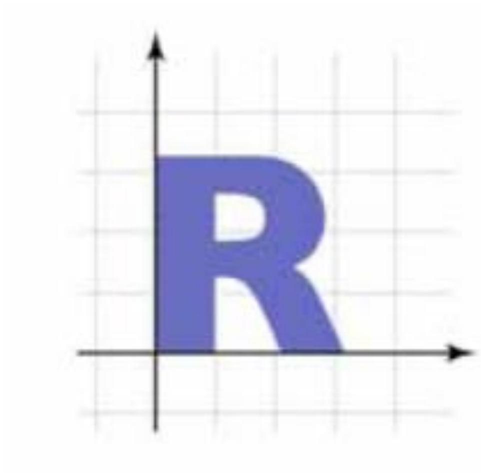


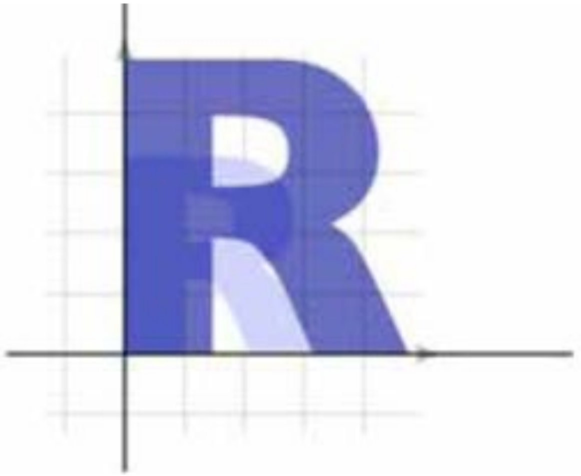


Affine Transform Gallery

- Uniform Scale:

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

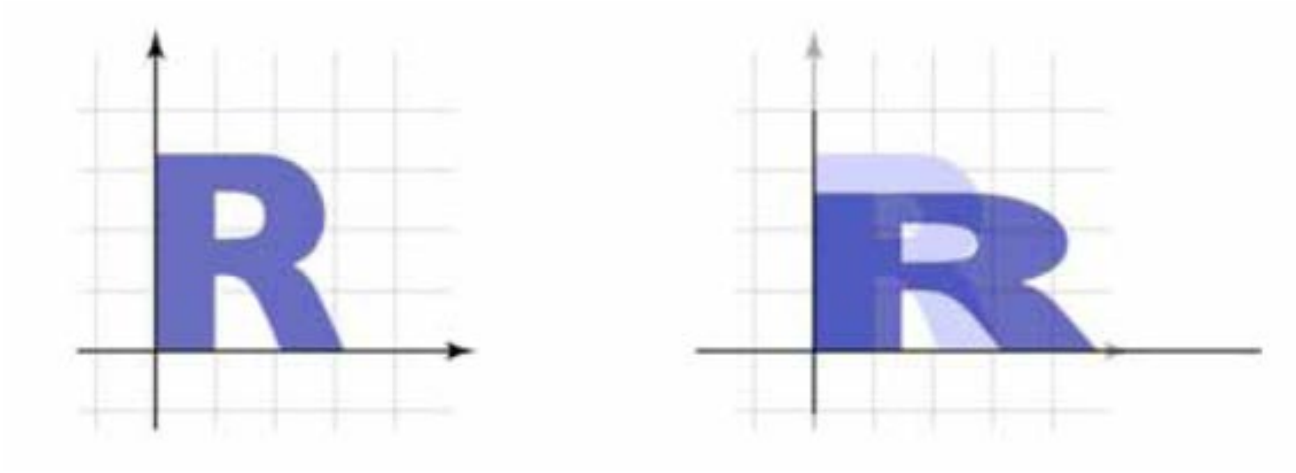




Affine Transform Gallery

- Nonuniform Scale:

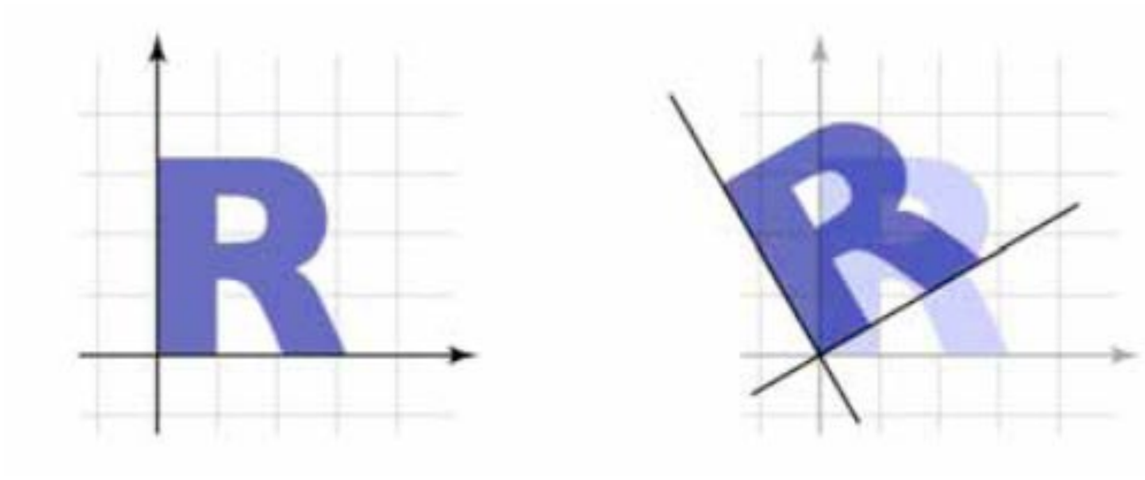
$$\begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1.5 & 0 & 0 \\ 0 & 0.8 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



Affine Transform Gallery

- Rotation:

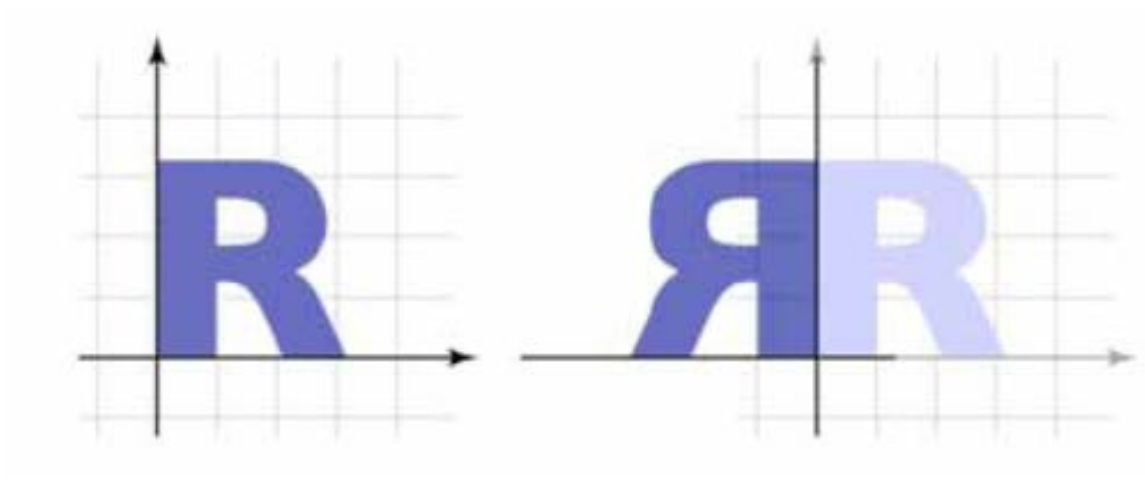
$$\begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.866 & -0.5 & 0 \\ 0.5 & 0.866 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



Affine Transform Gallery

- Reflection:
  - Special case of Scale

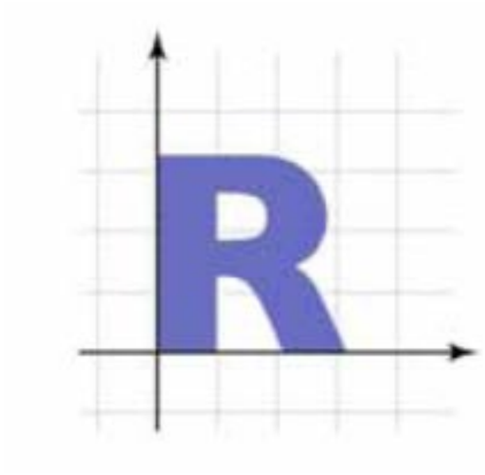
$$\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

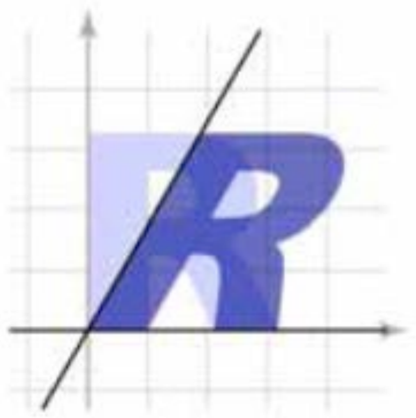


Affine Transform Gallery

- Shear:

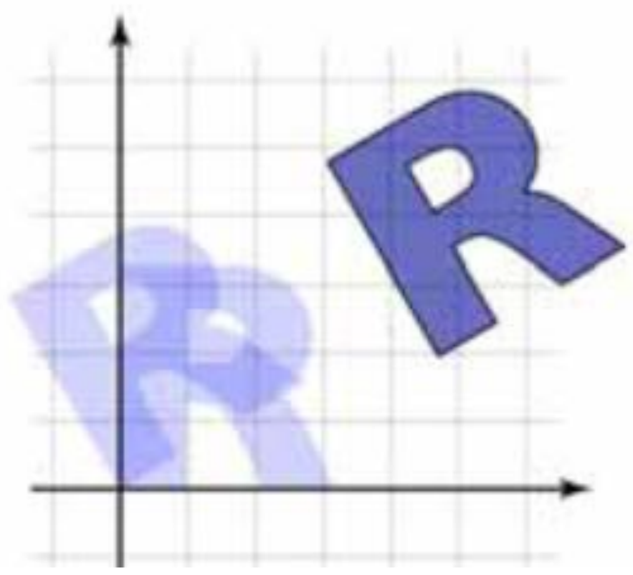
$$\begin{bmatrix} 1 & a & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1 & 0.5 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

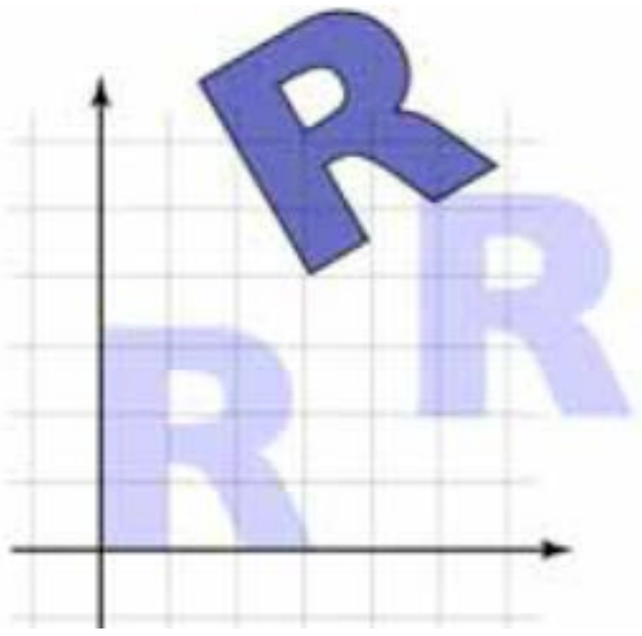




Compositing Transforms

- In general not commutative: order matters!


rotate, then translate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Compositing Transforms

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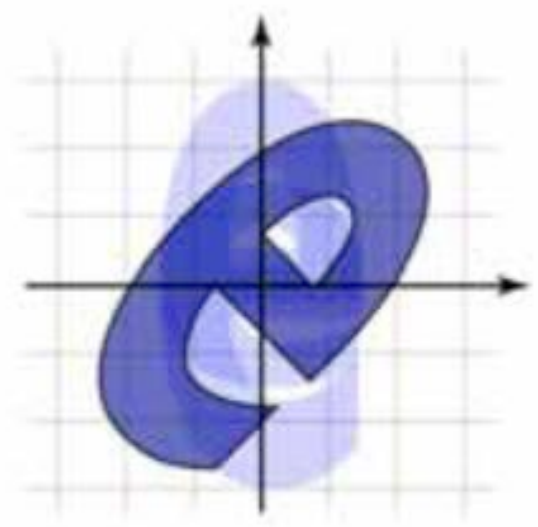
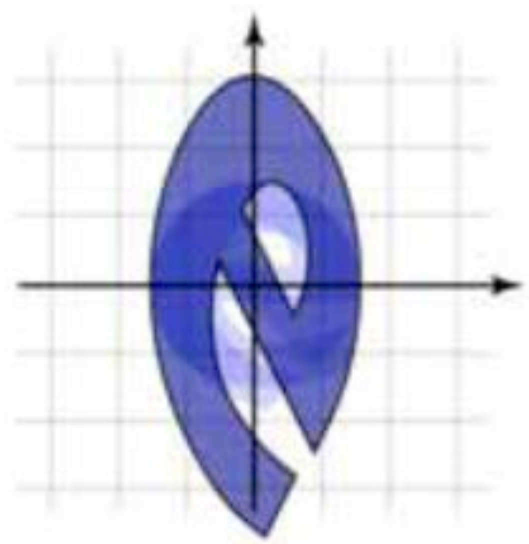
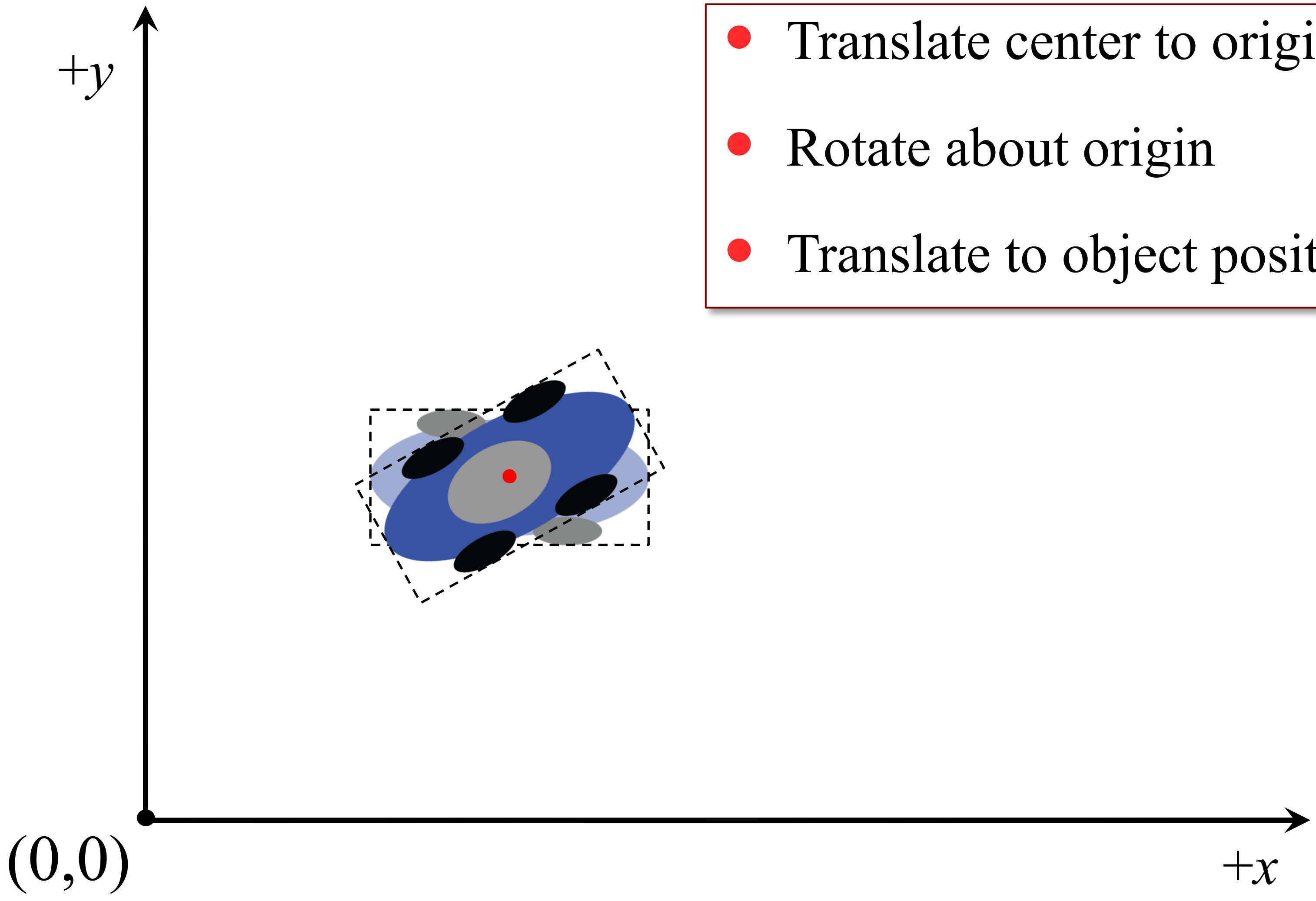


scale, then rotate



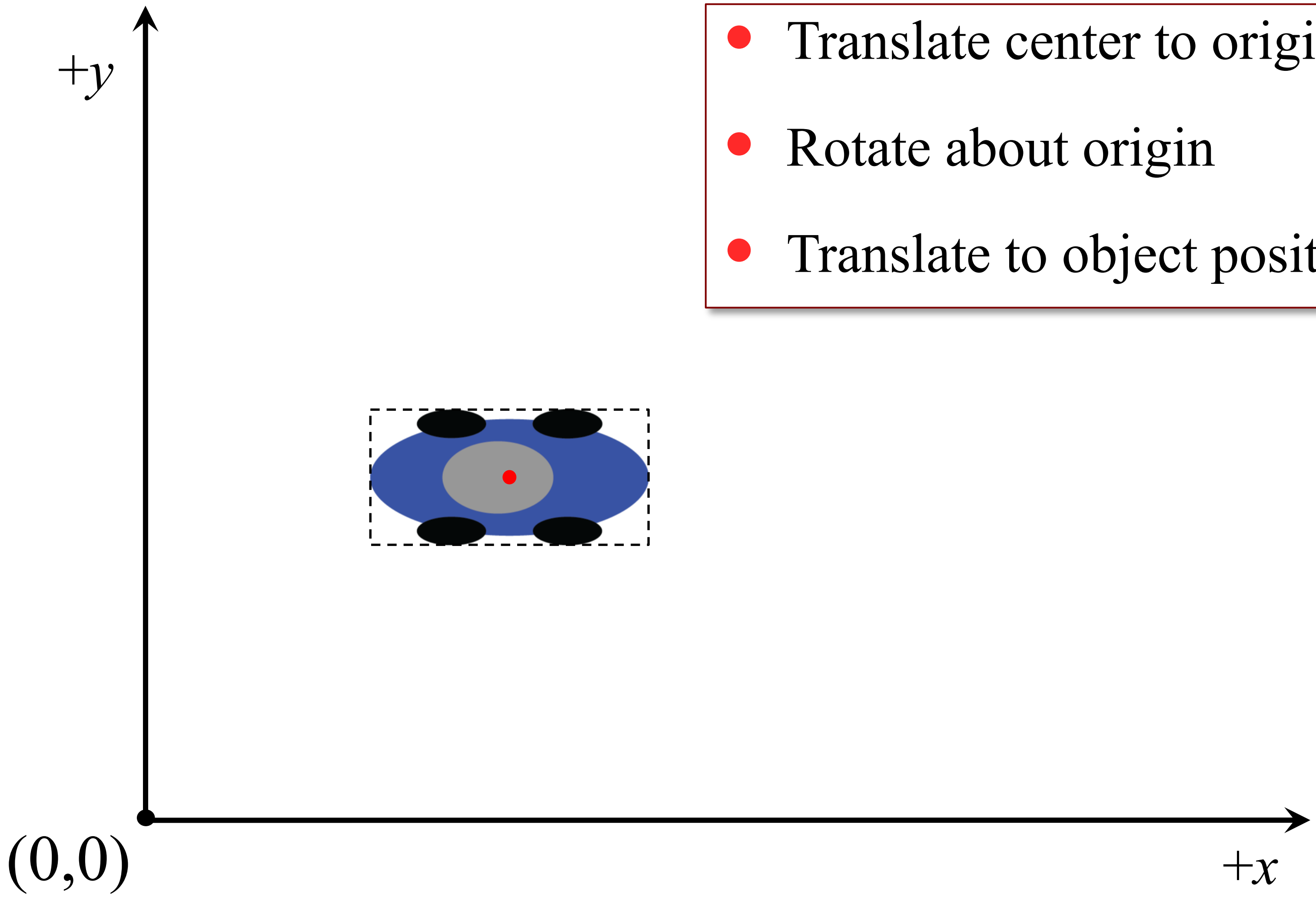
rotate, then scale

Rotating Object About Center



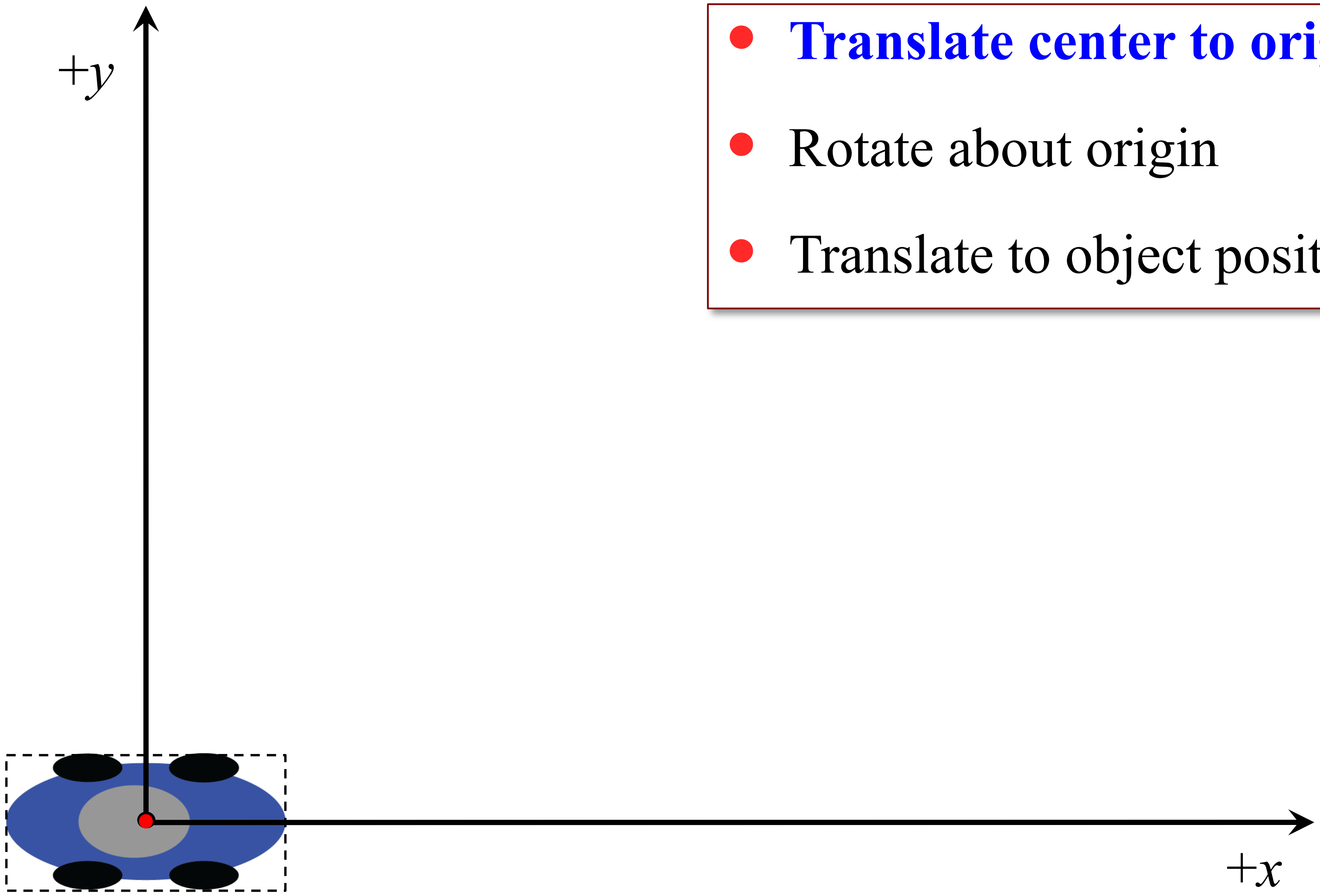
- Translate center to origin
- Rotate about origin
- Translate to object position

Rotating Object About Center



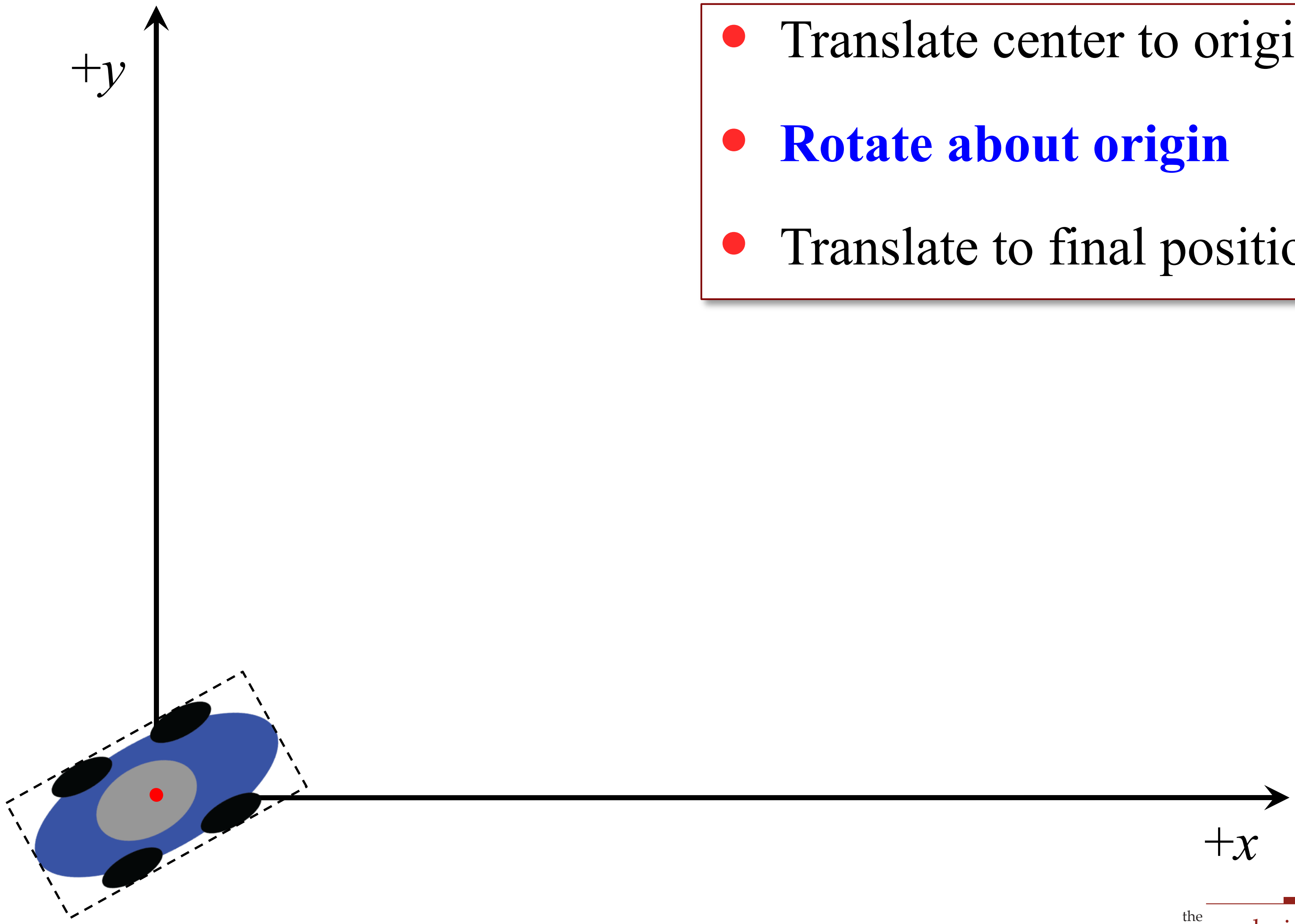
- Translate center to origin
- Rotate about origin
- Translate to object position

Rotating Object About Center



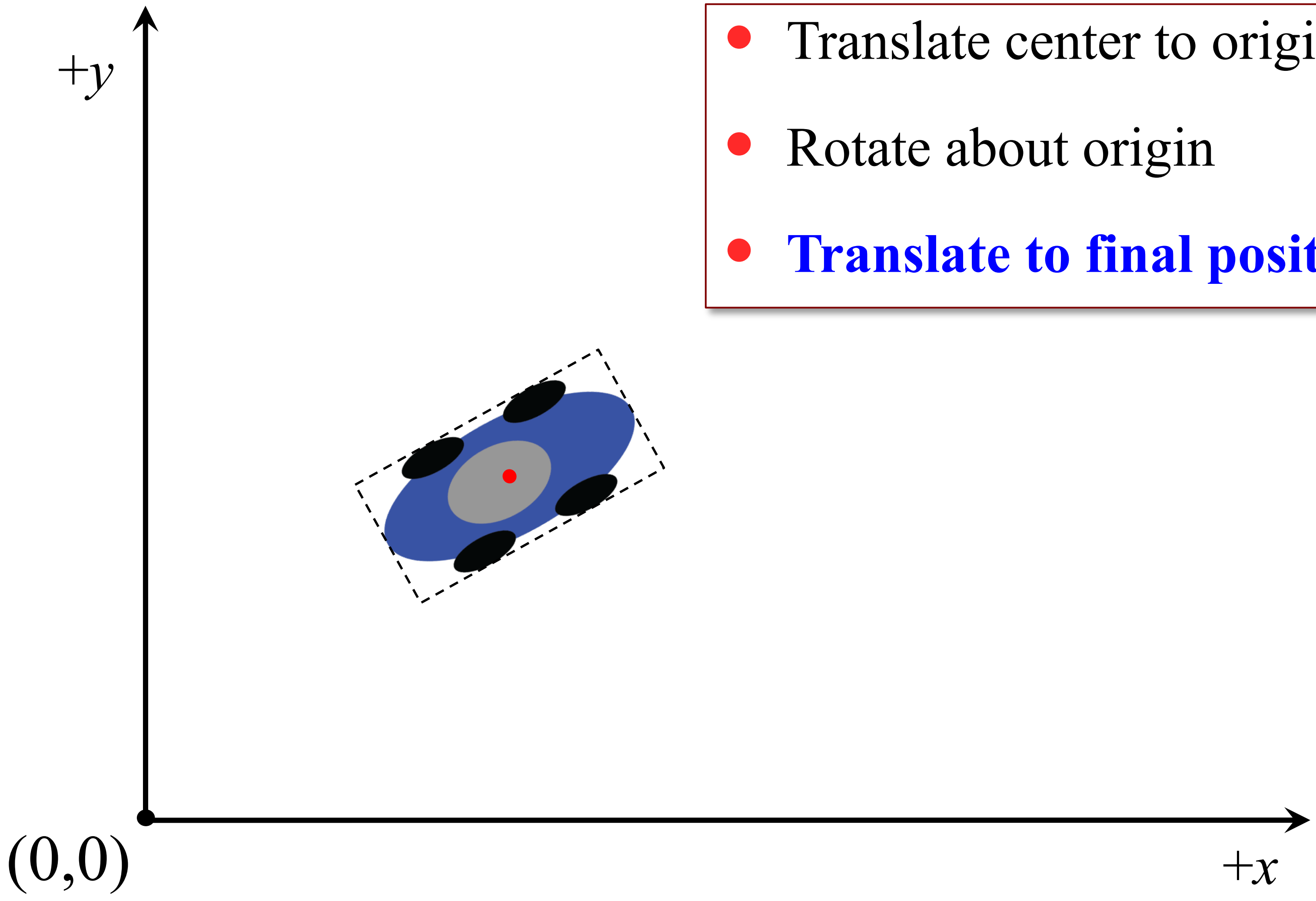
- **Translate center to origin**
- Rotate about origin
- Translate to object position

Rotating Object About Center



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

Rotating Object About Center



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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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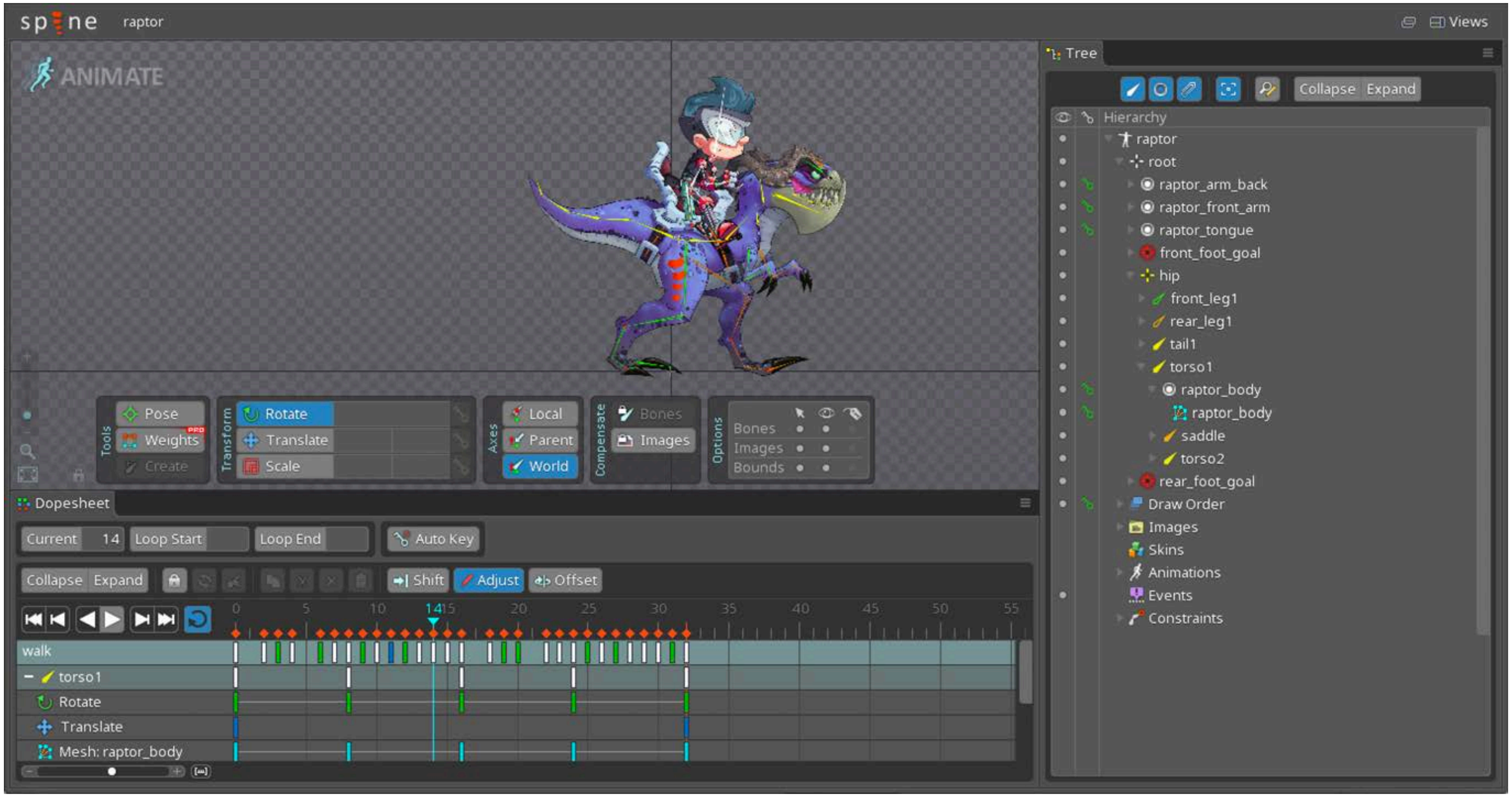
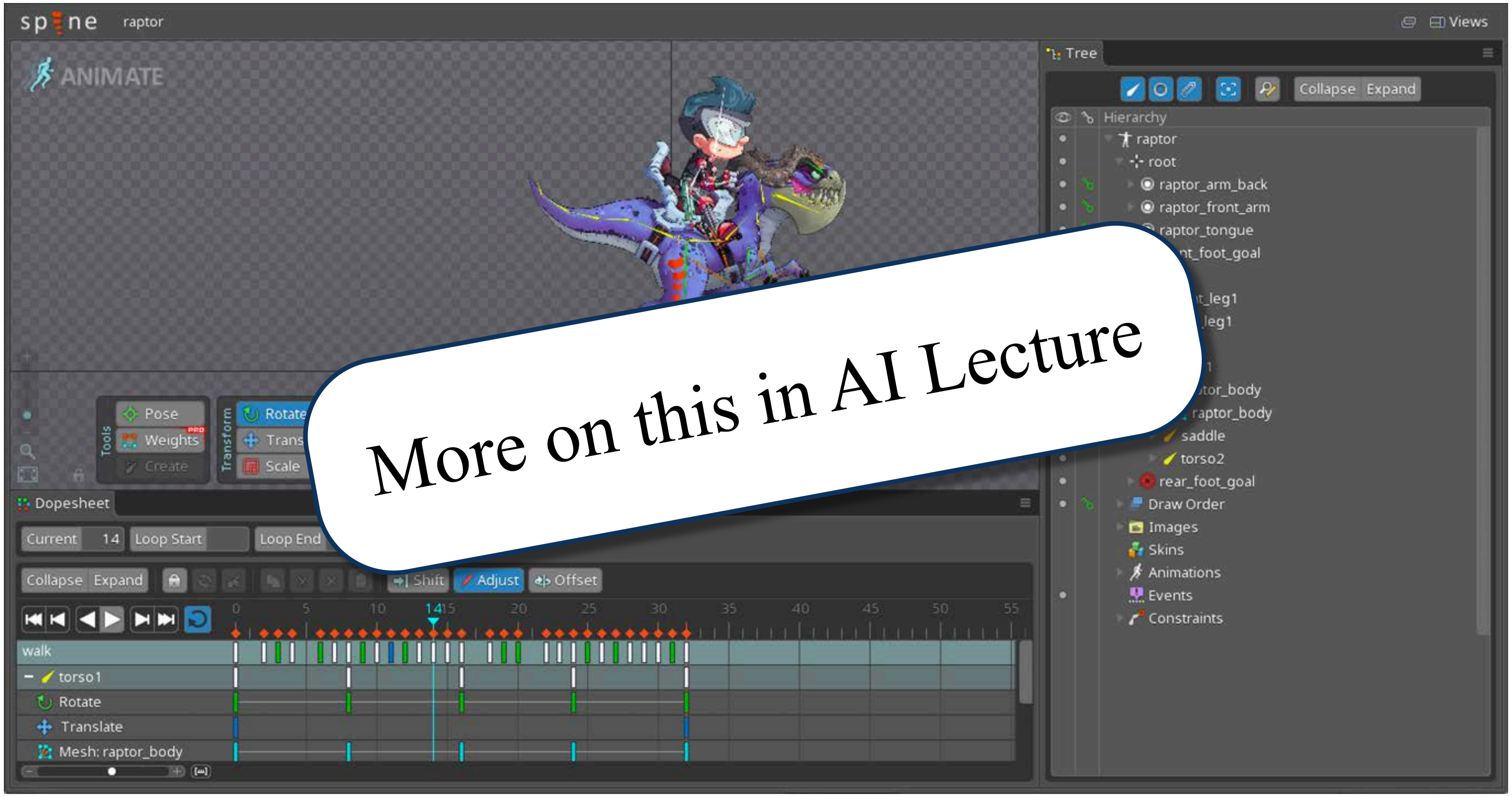
Spine Demo



spine raptor
Views
ANIMATE
Tree
Collapse Expand
Hierarchy
raptor
root
raptor_arm_back
raptor_front_arm
raptor_tongue
front_foot_goal
hip
front_leg1
rear_leg1
tail1
torso1
raptor_body
raptor_body
saddle
torso2
rear_foot_goal
Draw Order
Images
Skins
Animations
Events
Constraints
Tools
Pose
Weights
Create
Transform
Rotate
Translate
Scale
Axes
Local
Parent
World
Compensate
Bones
Images
Options
Bones
Images
Bounds
Dopesheet
Current 14
Loop Start
Loop End
Auto Key
Collapse Expand
Shift
Adjust
Offset
0 5 10 14 15 20 25 30 35 40 45 50 55
walk
torso1
Rotate
Translate
Mesh: raptor_body

Spine Demo



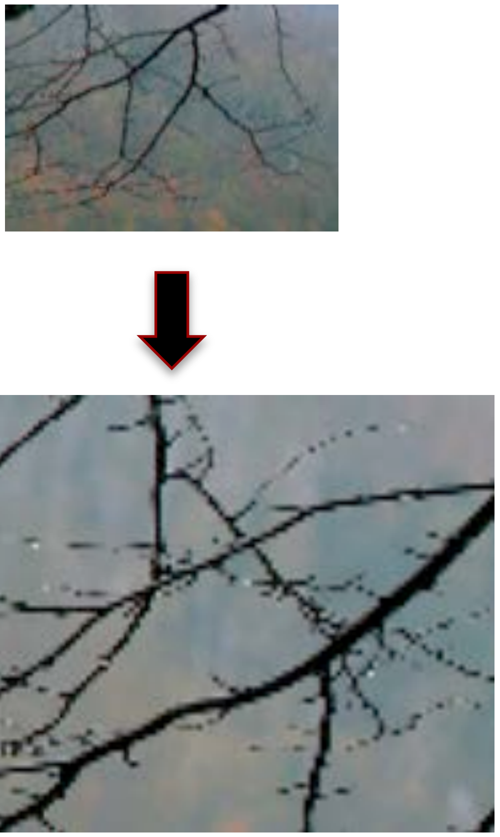
More on this in AI Lecture

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"