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

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- Drawing Perspective
  - Camera
  - Projections

- Drawing Primitives
  - Color and Textures
  - Polygons

  - bare minimum to draw graphics
  - side-scroller vs. top down
  - necessary for lighting & shadows
Graphics Lectures

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  - Projections

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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

Screen: (300,200)
Object: (0,0)

(0,0)
Historical Coordinate Systems

(0,0)

Screen: (300,200)  Object: (0,0)

2D Sprite Graphics
Historical Coordinate Systems

Screen: (300,200)  Object: (0,0)

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

Screen: (300,200)
Object: (0,0)

(0,0)

Screen: (300,200)
Object: (0,0)

(0,0)
Sprite Coordinate Systems

Screen: (300,200)  Object: (0,0)
Sprite Coordinate Systems

Screen: (300,200)  
Object: (0,0)
Sprite Coordinate Systems

Screen: (300,200)
Object: (0,0)
public void draw(float dt) {

    spriteBatch.begin();
spriteBatch.draw(image0);
spriteBatch.draw(image1, pos.x, pos.y);

    spriteBatch.end();

}
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”

- $T: \text{object coords} \rightarrow \text{screen coords}$
  - 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 $(a,b) = \text{color of screen at } (a,b)$
  - By drawing an image, you are transforming it

- $S$ an image; transformed image is $T(S)$
Example: Translation

- Simplest transformation: $T(v) = v + u$
  - Shifts object in direction $u$
  - Distance shifted is magnitude of $u$

- Used to place objects on screen
  - By default, object origin is screen origin
  - $T(v) = v + u$ 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

World origin

2D Sprite Graphics
Application: Scrolling

2D Sprite Graphics
Application: Scrolling

2D Sprite Graphics
Scrolling: Two Translations

- Place object in the World at point \( p = (x,y) \)
  - Basic drawing transform is \( T(v) = v+p \)

- Suppose Screen origin is at \( q = (x',y') \)
  - Then object is on the Screen at point \( p-q \)
  - \( S(v) = v-q \) transforms World coords to Screen
  - \( S \circ T(v) \) 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 the 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 Lab 1
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

Only supports a `TextureRegion`??
public void draw(float dt) {

    Vector2 pos = object.getPosition();

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

2D Sprite Graphics
Positioning in LibGDX

```java
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

```java
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();
}
```
Transform Gallery

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

\[
\begin{bmatrix}
  1.5 & 0 \\
  0 & 1.5
  \end{bmatrix}
\]

```javascript
affine.setToScaling(s,s);
```
**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:

\[
\begin{bmatrix}
  s_x & 0 \\
  0   & s_y
\end{bmatrix}
\begin{bmatrix}
  x \\
  y
\end{bmatrix}
= 
\begin{bmatrix}
  s_x x \\
  s_y y
\end{bmatrix}
\]

\[
\begin{bmatrix}
  1.5 & 0 \\
  0   & 0.8
\end{bmatrix}
\]

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

- Rotation:

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

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, $T(v+w) = T(v)+T(w)$
  • Translation transform is $T(v) = v+u$
  • $T(v)+T(w) = (v+u)+(w+u) = v+w+2u \neq T(v+w)$

• 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 \( 3 \times 3 \))

- Dimension is for calculation only
  - We are not in 3D-space **yet**
  - 3D transforms need 4D vectors, \( 4 \times 4 \) matrices

- Matrix4 because LibGDX supports 3D

2D Sprite Graphics
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 $T(v) = Mv+p$
  - 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:**

\[
\begin{bmatrix}
    s & 0 & 0 \\
    0 & s & 0 \\
    0 & 0 & 1
\end{bmatrix}
\]

\[
\begin{bmatrix}
    1.5 & 0 & 0 \\
    0 & 1.5 & 0 \\
    0 & 0 & 1
\end{bmatrix}
\]

2D Sprite Graphics
Affine Transform Gallery

• Nonuniform Scale:

\[
\begin{bmatrix}
  s_x & 0 & 0 \\
  0 & s_y & 0 \\
  0 & 0 & 1
\end{bmatrix}
\]

\[
\begin{bmatrix}
  1.5 & 0 & 0 \\
  0 & 0.8 & 0 \\
  0 & 0 & 1
\end{bmatrix}
\]

2D Sprite Graphics
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:

\[
\begin{bmatrix}
1 & a & 0 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
1 & 0.5 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{bmatrix}
\]
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
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

Translation formulas:

\[
\begin{align*}
\text{Translate center to origin} & : \mathbf{v}_{\text{translation}} = (x_{\text{center}}, y_{\text{center}}) \\
\text{Rotate about origin} & : \mathbf{v}_{\text{rotation}} = \mathbf{R}(\theta) \mathbf{v}_{\text{object}} \\
\text{Translate to object position} & : \mathbf{v}_{\text{final}} = \mathbf{v}_{\text{rotation}} + \mathbf{v}_{\text{translation}}
\end{align*}
\]
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
Transforms and Modular Animation

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  - **Example**: Spriter, Spine
  - Great for visualizing design
Spine Demo

Scene Graphs
More on this in AI Lecture
A Word About Scaling

- If making smaller, it drops out pixels
  - Suppose $T(v) = 0.5v$
  - $(0,0) = T(0,0)$; 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 $T(v) = 2v$
  - $(0,1) = T(0,0.5)$; 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”