Lecture 16

Color and Textures
Take Away For Today

- **Image color and composition**
  - What is the RGB model for images?
  - What does alpha represent?
  - How does alpha composition work?

- **Graphics primitives**
  - How do primitives differ from sprites?
  - How does LibGDX support primitives?
  - How do we combine sprites and primitives?
Drawing Multiple Objects

- Objects are on a **stack**
  - Images are *layered*
  - Drawn in order given

- Uses **color composition**
  - Often just draws last image
  - What about **transparency**?

- We need to understand…
  - How color is **represented**
  - How colors **combine**
Color Representation

- Humans are **Trichromatic**
  - Any color a blend of three
  - Images from only 3 colors

- Additive Color
  - Each color has an intensity
  - Blend by adding intensities

- Computer displays:
  - Light for each “channel”
  - Red, green and blue

- Aside: Subtractive Color
  - Learned in primary school
  - For pigments, not light
Color Blending Example
Each color has an **intensity**
- Measures amount of light of that color
- 0 = absent, 1 = maximum intensity

Real numbers take up a lot of space
- **Compact representation**: one byte (0-255)
- As good as human eye can distinguish

But graphics algorithms require [0, 1]
- Use [0, 255] for *storage only*
- intensity = bits/255.0
- bits = floor(intensity*255)
Color Representation

- Intensity for three colors: 3 bytes or 24 bits

```
01011010 00000010 00011111 01011010
```

HTML Color

<table>
<thead>
<tr>
<th>#5A</th>
<th>02</th>
<th>1F</th>
<th>Not Supported</th>
</tr>
</thead>
</table>

- Store as a 32 bit int; use bit ops to access
  - red: 0x000000FF & integer
  - green: 0x000000FF & (integer >> 8)
  - blue: 0x000000FF & (integer >> 16)

- Most integers are actually 4 bytes; what to do?
The Alpha Channel

- Only used in **color composition**
- Does *not* correspond to a physical light source
  - Allows for transparency of overlapping objects
  - Without it the colors are written atop another
Color Composition

- Trivial example: Video crossfade
  - Smooth transition from one scene to another.

- Note sums weight to 1.0
  - No unexpected brightening or darkening
  - No out-of-range results

- This is an example of **linear interpolation**

\[
\begin{align*}
r_C &= tr_A + (1 - t)r_B \\
g_C &= tg_A + (1 - t)g_B \\
b_C &= tb_A + (1 - t)b_B
\end{align*}
\]

per pixel calculation
Color Composition

• Trivial example: Video crossfade
  • Smooth transition from one scene to another.

![Trivial example: Video crossfade](image)

- Smooth transition from one scene to another.

\[
\begin{align*}
    r_C &= tr_A + (1 - t)r_B \\
    g_C &= tg_A + (1 - t)g_B \\
    b_C &= tb_A + (1 - t)b_B
\end{align*}
\]

per pixel calculation

• Note sums weight to 1.0
  • No unexpected brightening or darkening
  • No out-of-range results

• This is an example of **linear interpolation**
**Color Composition**

- **Trivial example: Video crossfade**
  - Smooth transition from one scene to another.

  ![Example Images](image)

  \[ r_C = tr_A + (1 - t)r_B \]

  \[ g_C = tg_A + (1 - t)g_B \]

  \[ b_C = tb_A + (1 - t)b_B \]

- **Note sums weight to 1.0**
  - No unexpected brightening or darkening
  - No out-of-range results

- **This is an example of linear interpolation**
Color Composition

- Trivial example: Video crossfade
  - Smooth transition from one scene to another.

- Note sums weight to 1.0
  - No unexpected brightening or darkening
  - No out-of-range results

- This is an example of **linear interpolation**

\[
\begin{align*}
  r_C &= tr_A + (1 - t)r_B \\
  g_C &= tg_A + (1 - t)g_B \\
  b_C &= tb_A + (1 - t)b_B
\end{align*}
\]
per pixel calculation

[Chuang et al. Corel]
Color Composition

- Trivial example: Video crossfade
  - Smooth transition from one scene to another.

Note sums weight to 1.0
- No unexpected brightening or darkening
- No out-of-range results

This is an example of linear interpolation

\[
\begin{align*}
r_C &= tr_A + (1 - t)r_B \\
g_C &= tg_A + (1 - t)g_B \\
b_C &= tb_A + (1 - t)b_B
\end{align*}
\]

per pixel calculation
Forefront and Background

- In many cases, just adding is not enough
  - Want some elements in composite, not others
  - Do not want transparency of crossfade

- How we compute new image varies with position.

- Need to store a tag indicating parts of interest

[Chuang et al./Corel]
Binary Image Mask

- First idea: Store one bit per pixel
  - Answers question “Is this pixel in foreground?”

- Does not work well near the edges
**Binary Image Mask**

- **First idea:** Store one bit per pixel
  - Answers question “Is this pixel in foreground?”

- **Does not work well near the edges**
Binary Image Mask

- First idea: Store one bit per pixel
  - Answers question “Is this pixel in foreground?”

- Does not work well near the edges
Partial Pixel Coverage

**Problem**: Boundary neither foreground nor background

![Diagram of partial pixel coverage](image)
Partial Pixel Coverage

**Solution**: Interpolate on the border (Not exact, but *fast*)
**Alpha Compositing**

- Formalized in 1984 by Porter & Duff
- **Store fraction of pixel covered; call it** $\alpha$

\[
C = A \text{ over } B
\]

\[
r_C = \alpha_A r_A + (1 - \alpha_A) r_B
\]

\[
g_C = \alpha_A g_A + (1 - \alpha_A) g_B
\]

\[
b_C = \alpha_A b_A + (1 - \alpha_A) b_B
\]

- **Clean implementation; 8 more bits makes 32**
  - 2 multiplies + 1 add for compositing
Alpha Compositing Example

- Repeat previous with grey scale mask
- Edges are much better now
Alpha Compositing Example

- Repeat previous with grey scale mask
  - Edges are much better now
Compositing in LibGDX

- `spriteBatch.setBlendFunction(src, dst);`

  OpenGL Constants

  - **General Formula:** $c_C = (\text{src})c_A + (\text{dst})c_B$

- **Alpha Blending**
  - `src = GL20.GL_SRC_ALPHA` \hspace{1cm} \(a_A\)
  - `dst = GL20.GL_ONE_MINUS_SRC_ALPHA` \hspace{1cm} \((1-a_A)\)

- Colors may be **premultiplied:** \(c' = ca\)
  - `src = GL20.GL_ONE`
  - `dst = GL20.GL_ONE_MINUS_SRC_ALPHA`
Compositing in LibGDX

- `spriteBatch.setBlendFunction(src, dst);`

  OpenGL Constants

- **General Formula**: \( c_C = (src)c_A + (dst)c_B \)

- **Additive Blending** (not premultiplied)
  - \( src = GL20.GL_SRC_ALPHA \)
  - \( dst = GL20.GL_ONE \)

- **Opaque** (no blending at all)
  - \( src = GL20.GL_ONE \)
  - \( dst = GL20.GL_ZERO \)
The Problem with Sprites

- Sprites drawn by artist
  - Distort with transforms
  - Major changes require new art from artist
  - Inefficient collaboration

- Sprite-free graphics?
  - Simple geometries
  - Particle effects
  - Dynamic shapes
Triangles in Computer Graphics

- Everything made of **triangles**
  - Mathematically “nice”
  - Hardware support (GPUs)

- Specify with **three vertices**
  - Coordinates of corners

- Composite for complex shapes
  - Array of vertex objects
  - Each 3 vertices = triangle

Color & Texture
Triangulation of Polygons
Triangulation of Polygons
Triangulation of Polygons
Triangulation of Polygons
Round Shapes?
Round Shapes?
ShapeRenderer in LibGDX

- Tool to draw triangles
  - Specify a general shape
  - Makes the triangles for you
- Works like a SpriteBatch
  - Has a begin/end
  - Can set default color
  - Several draw commands
- Can mix with SpriteBatch
  - But not at the same time!
  - End one before begin other
ShapeRenderer in LibGDX

- Tool to draw triangles
  - Specify a general shape
  - Makes the triangles for you
- Works like a SpriteBatch
  - Has a begin/end
  - Can set default color
  - Several draw commands
- Can mix with SpriteBatch
  - But not at the same time!
  - End one before begin other

```java
render.circle(200, 200, 100, 5);
```

Number of triangles
ShapeRenderer Example

```java
render.begin(ShapeRenderer.ShapeType.Filled);
render.setColor(Color.BLUE);
render.circle(200, 200, 100, 8);
render.end();

render.begin(ShapeRenderer.ShapeType.Line);
render.setColor(Color.RED);
render.circle(200, 200, 100, 8);
render.end();
```
ShapeRenderer Example

render.begin(ShapeRenderer.ShapeType.Filled);
render.setColor(Color.BLUE);
render.circle(200, 200, 100, 8);
render.end();

render.begin(ShapeRenderer.ShapeType.Line);
render.setColor(Color.RED);
render.circle(200, 200, 100, 8);
render.end();
ShapeRenderer Example

```java
render.begin(ShapeRenderer.ShapeType.Filled);
render.setColor(Color.BLUE);
render.circle(200, 200, 100, 8);
render.end();

render.begin(ShapeRenderer.ShapeType.Line);
render.setColor(Color.RED);
render.circle(200, 200, 100, 8);
render.end();
```

Note separate pass for filled, outline
Textures

2D Image File

Mapped On To Polygonal Shape
Simple Texturing in LibGDX

- **PolygonSpriteBatch** handles 90% of all cases
  - Works like a normal SpriteBatch
  - But now specify image and polygon
  - Entirely replaced SpriteBatch in Lab 4

- Uses the **PolygonRegion** class
  - Way to specify what part of image to use
  - Specify as a collection of vertices
  - Specify using **pixel positions**, **not texture coords**
  - See PolygonObstacle in Lab 4
PolygonRegion Example

- Create vertices by **pixel pos**
  - Example texture is 124x124
  - Preferences set to wrap
  - Store as an array of floats
- Must convert into triangles
  - Each vertex has an index
  - Given by position in array
  - Create array of indices
- Construct PolygonRegion
  - Specify texture
  - Specify vertices+triangles

verts = \{0, 0, 0, 64, 192, 128, 128, 0\}
PolygonRegion Example

- Create vertices by pixel pos
  - Example texture is 124x124
  - Preferences set to wrap
  - Store as an array of floats

- Must convert into triangles
  - Each vertex has an index
  - Given by position in array
  - Create array of indices

- Construct PolygonRegion
  - Specify texture
  - Specify vertices+triangles

verts = {0,0,0,64,192,128,128,0}
tris = {0,1,3,3,1,2}
new PolygonRegion(img, verts, tris)

verts = \{0,0,0,64,192,128,128,0\}
tris = \{0,1,3,3,1,2\}

- Create vertices by pixel pos
  - Example texture is 124x124
  - Preferences set to wrap
  - Store as an array of floats
- Must convert into triangles
  - Each vertex has an index
  - Given by position in array
  - Create array of indices
- **Construct** PolygonRegion
  - Specify texture
  - Specify vertices+triangles
What If I Know OpenGL?

- Use the **GL20** (OpenGLES 2.0) object
  - Standard OpenGL functions are its methods
  - Standard OpenGL values are its constants

- There is a **GL30** (OpenGLES 3.0), but
  - Flakey support for Mac Java or mobile devices
  - Not really necessary for this class

- See **Programming Lab 2** for examples
  - Uses a custom OpenGL shader
  - Also advanced LibGDX classes like Mesh
OpenGL Texturing

Texture Coordinates (even if not square)

Interpolates

Triangle Coordinates

Specify Both!

(0,0) (1,0)

(0,1) (1,1)

(0,4) (3,4)

(0,1) (1,1)

(1,0) (4,0)
OpenGL Texturing

Texture Coordinates (even if not square)

Triangle Coordinates (more than one triangle)
Summary

- Computer images defined by **color channels**
  - Three visible channels: red, green, blue

- Sprites combined via **compositing**
  - Alpha = percentage color in foreground

- Can use **triangles** instead of sprites
  - Complex shapes defined by arrays of triangles

- **Textures** generalize the notion of color
  - 2D image that is used to “color” triangle
  - Need triangle coordinates **and** texture coordinates