Drawing Objects in the World

Introduction

Ideally, a video game engine should provide proper abstractions to support designing and building games in meaningful contexts. For example, when designing a soccer game, instead of a single square with a fixed ±1.0 drawing range, a game engine should provide proper utilities to support designs in the context of players running on a soccer field. This high-level abstraction requires the encapsulation of basic operations with data hiding and meaningful functions for setting and receiving the desired results.

This chapter focuses on creating the fundamental abstractions to support drawing. Based on the soccer game example, the support for drawing in an effective game engine would likely include the ability to easily create the soccer players, control their size and orientations, and allow them to be moved and drawn on the soccer field. Additionally, to support proper presentation, the game engine must allow drawing to specific subregions on the canvas so that a distinct game status can be displayed at different subregions, such as the soccer field in one subregion and player statistics and scores in another subregion.

This chapter identifies proper abstraction entities for the basic drawing operations, introduces operators that are based on foundational mathematics to control the drawing, overviews the WebGL tools for configuring the canvas to support subregion drawing, defines JavaScript classes to implement these concepts, and integrates these implementations into the game engine while maintaining the organized structure of the source code.

Encapsulating Drawing

Although the ability to draw is one of the most fundamental functionalities of a game engine, the details of how drawings are implemented are generally a distraction to gameplay programming. For example, it is important to create, control the locations of, and draw soccer players in a soccer game. However, exposing the details of how each player is actually defined (by a collection of vertices that form triangles) can quickly overwhelm and complicate the game development process. Thus, it is important for a game engine to provide a well-defined abstraction interface for drawing operations.

With a well-organized source code structure, it is possible to gradually and systematically increase the complexity of the game engine by implementing new concepts with localized changes to the corresponding folders. The first task is to expand the engine to support the encapsulation of drawing such that it becomes possible to manipulate drawing operations as a logical entity or as an object that can be rendered.

Note In the context of computer graphics and video games, the word render refers to the process of changing the color of pixels corresponding to an abstract representation. For example, in the previous chapter, you learned how to render a square.

The Renderable Objects Project

This project introduces the `Renderable` class to encapsulate the drawing operation. Over the next few projects, you will learn more supporting concepts to refine the implementation of the `Renderable` class such that multiple instances can be created and manipulated.

The goals of the project are as follows:

- To reorganize the source code structure in anticipation for functionality increases
- To support game engine internal resource sharing
- To introduce a systematic interface for the game developer via the `index.js` file
- To begin the process of building a class to encapsulate drawing operations by first abstracting the related drawing functionality
- To demonstrate the ability to create multiple `Renderable` objects

Source Code Structure Reorganization

Before introducing additional functionality to the game engine, it is important to recognize some shortfalls of the engine source code organization from the previous project. In particular, take note of the following:

1. The `core.js` source code file contains the WebGL interface, engine initialization, and drawing functionalities. These should be modularized to support the anticipated increase in system complexity.
2. A system should be defined to support the sharing of game engine internal resources. For example, `SimpleShader` is responsible for interfacing from the game engine to the GLSL shader compiled from the `simple_vs.glsl` and `simple_fs.glsl` source code files. Since there is only one copy of the compiled shader, there only needs to be a single instance of the `SimpleShader` object. The game engine should facilitate this by allowing the convenient creation and sharing of the object.
3. As you have experienced, the JavaScript `export` statement can be an excellent tool for hiding detailed implementations. However, it is also true that determining which classes or modules to import from a number of files can be confusing and overwhelming in a large and complex system, such as the game engine you are about to develop. An easy to work with and systematic interface should be provided such that the game developer, users of the game engine, can be insulated from these details.

In the following section, the game engine source code will be reorganized to address these issues.

Define a WebGL-Specific Module

The first step in source code reorganization is to recognize and isolate functionality that is internal and should not be accessible by the clients of the game engine:

1. In your project, under the `src/engine` folder, create a new folder and name it `core`. From this point forward, this folder will contain all functionality that is internal to the game engine and will not be exported to the game developers.

2. Create a new source code file in the `src/engine/core` folder, name it `gl.js`, and define WebGL's initialization and access methods:

```
"use strict"
let mCanvas = null;
let mGL = null;

function get() { return mGL; }

function init(htmlCanvasID) {
  mCanvas = document.getElementById(htmlCanvasID);
  if (mCanvas == null)
   throw new Error("Engine init [" +
                    htmlCanvasID + "] HTML element id not found");
  // Get webgl and bind to the Canvas area ands
  // store the results to the instance variable mGL
  mGL = mCanvas.getContext("webgl2");
  if (mGL === null) {
   document.write("<br><b>WebGL 2 is not supported!</b>");
   return;
  }
}

export {init, get}
```

3. You can move the `vertex_buffer.js` source code file from the previous project into the `src/engine/core` folder. The details of the primitive vertices are internal to the game engine and should not be visible or accessible by the clients of the game engine.

4. Modify the `import` of `vertex_buffer.js` to reference the new `glSys` instead of `core`.

```
import * as glSys from "./gl.js";
```

5. Modify the `import` of `simple_shader.js` to reference the new `glSys` instead of `core` and to reference the new location of `vertex_buffer.js`.

```
import * as glSys from "./core/gl.js";
import * as vertexBuffer from "./core/vertex_buffer.js";
```

6. Modify the `let` statement in the `init()` function of `vertex_buffer.js`. Also modify ALL OCCURENCES of this let statement in `simple_shader.js` within 1) the

constructor, 2) the loadAndCompileShader() function and 3) the activate() functions to reference the new get() function provided by glSys.

```
let gl = core.getGL();      ➔     let gl = glSys.get();
```

Notice that the init() function is identical to the initWebGL() function in core.js from the previous project. Unlike the previous core.js source code file, the gl.js file contains only WebGL-specific functionality.

Define a System for Internal Shader Resource Sharing

Since only a single copy of the GLSL shader is created and compiled from the simple_vs.glsl and simple_fs.glsl source code files, only a single copy of SimpleShader object is required within the game engine to interface with the compiled shader. You will now create a simple resource sharing system to support future additions of different types of shaders.

Create a new source code file in the src/engine/core folder, name it shader_resources.js, and define the creation and accessing methods for SimpleShader.

Note Recall from the previous chapter that the SimpleShader class is defined in the simple_shader.js file which is located in the src/engine folder. Remember to copy all relevant source code files from the previous project.

```
"use strict";
import SimpleShader from "../simple_shader.js";
// Simple Shader
let kSimpleVS = "src/glsl_shaders/simple_vs.glsl"; // to VertexShader
let kSimpleFS = "src/glsl_shaders/simple_fs.glsl"; // to FragmentShader
let mConstColorShader = null;

function createShaders() {
  mConstColorShader = new SimpleShader(kSimpleVS, kSimpleFS);
}

function init() {
  createShaders();
}

function getConstColorShader() { return mConstColorShader; }

export {init, getConstColorShader}
```

Note Variables referencing constant values have names that begin with lowercase “k”, as in kSimpleVS.

Since the shader_resources module is located in the src/engine/core folder, the defined shaders are shared within and cannot be accessed from the clients of the game engine.

Define an Access File for the Game Developer

You will define an engine access file, index.js, to implement the fundamental functions of the game engine and to serve a similar purpose as a C++ header file, the import statement in Java, or the using statement in C#, where functionality can be readily accessed without in-depth knowledge of the engine source code structure. That is, by importing index.js, the client can access all the components and functionality from the engine to build their game.

1. Create index.js file in the src/engine folder; import from gl.js, vertex_buffer.js, and shader_resources.js; and define the init() function to initialize the game engine by calling the corresponding init() functions of the three imported modules:

```
// local to this file only
import * as glSys from "./core/gl.js";
import * as vertexBuffer from "./core/vertex_buffer.js";
import * as shaderResources from "./core/shader_resources.js";

// general engine utilities
function init(htmlCanvasID) {
  glSys.init(htmlCanvasID);
  vertexBuffer.init();
  shaderResources.init();
}
```

2. Define the clearCanvas() function to clear the drawing canvas:

```
function clearCanvas(color) {
  let gl = glSys.get();
  gl.clearColor(color[0], color[1], color[2], color[3]);
  gl.clear(gl.COLOR_BUFFER_BIT); // clear to the color set
}
```

3. Now, to properly expose the Renderable symbol to the clients of the game engine, make sure to import such that the class can be properly exported. The Renderable class will be introduced in details in the next section. (NOTE: There probably should be some indication to put this near the top of the file)

```
// general utilities
import Renderable from "./renderable.js";
```

4. Finally, remember to export the proper symbols and functionality for the clients of the game engine: (NOTE: There probably should be some indication to put this near the bottom of the file)

```
export  default {
   // Util classes
   Renderable,
   // functions
   init, clearCanvas
}
```

With proper maintenance and update of this `index.js` file, the clients of your game engine, the game developers, can simply import from the `index.js` file to gain access to the entire game engine functionality without any knowledge of the source code structure. Lastly, notice that the `glSys`, `vertexBuffer`, and `shaderResources` internal functionality defined in the `engine/src/core` folder are not exported by `index.js` and thus are not accessible to the game developers.

The Renderable Class

At last, you are ready to define the `Renderable` class to encapsulate the drawing process:

1. Define the `Renderable` class in the game engine by creating a new source code file in the `src/engine` folder, and name the file `renderable.js`.

2. Open `renderable.js`, import from `gl.js` and `shader_resources.js`, and define the `Renderable` class with a constructor to initialize a reference to a shader and a color instance variable. Notice that the shader is a reference to the shared `SimpleShader` instance defined in `shader_resources`.

```
import * as glSys from "./core/gl.js";
import * as shaderResources from "./core/shader_resources.js";

class Renderable {
   constructor() {
    this.mShader = shaderResources.getConstColorShader();
    this.mColor = [1, 1, 1, 1]; // color of pixel
   }
... implementation to follow ...
}
```

3. As part of the implementation, define a `draw()` function for `Renderable`:

```
draw() {
  let gl = glSys.get();
  this.mShader.activate(this.mColor);
  gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4);
}
```

Notice that it is important to activate the proper GLSL shader in the GPU by calling the `activate()` function before sending the vertices with the `gl.drawArrays()` function.

4. Define the getter and setter functions for the color instance variable:

```
setColor(color) {this.mColor = color; }
getColor() { return this.mColor; }
```

5. Export the `Renderable` symbol as default to ensure this identifier cannot be renamed:

```
export default Renderable;
```

Though this example is simple, it is now possible to create and draw multiple instances of the `Renderable` objects with different colors.

Testing the Renderable Object

To test `Renderable` objects in `MyGame`, we replace the existing constructor and with one that creates white and red instances are created and drawn as follows (be sure not to delete the `window.onload` functionality that follows the constructor):

```
// import from engine/index.js for all engine symbols
import engine from "../engine/index.js";

class MyGame {
  constructor(htmlCanvasID) {
    // Step A: Initialize the webGL Context
    engine.init(htmlCanvasID);
    // Step B: Create the Renderable objects:
    this.mWhiteSq = new engine.Renderable();
    this.mWhiteSq.setColor([1, 1, 1, 1]);
    this.mRedSq = new engine.Renderable();
    this.mRedSq.setColor([1, 0, 0, 1]);
    // Step C: Draw!
    engine.clearCanvas([0, 0.8, 0, 1]);  // Clear the canvas
    // Step C1: Draw Renderable objects with the white shader
    this.mWhiteSq.draw();
    // Step C2: Draw Renderable objects with the red shader
    this.mRedSq.draw();
```

```
    }
}
```

Notice that the `import` statement is modified to import from the engine access file, `index.js`. Additionally, the `MyGame` constructor is modified to include the following steps:

1. Step A initializes the engine.
2. Step B creates two instances of `Renderable` and sets the colors of the objects accordingly.
3. Step C clears the canvas; steps C1 and C2 simply call the respective `draw()` functions of the white and red squares. Although both of the squares are drawn, for now, you are only able to see the last of the drawn squares in the canvas. Please refer to the following discussion for the details.

Observations
Run the project and you will notice that only the red square is visible! What happens is that both of the squares are drawn to the same location. Being the same size, the two squares simply overlap perfectly. Since the red square is drawn last, it overwrites all the pixels of the white square. You can verify this by commenting out the drawing of the red square (comment out the line `mRedSq.draw()`) and rerunning the project. An interesting observation to make is that objects that appear in the front are drawn last (the red square). You will take advantage of this observation much later when working with transparency.

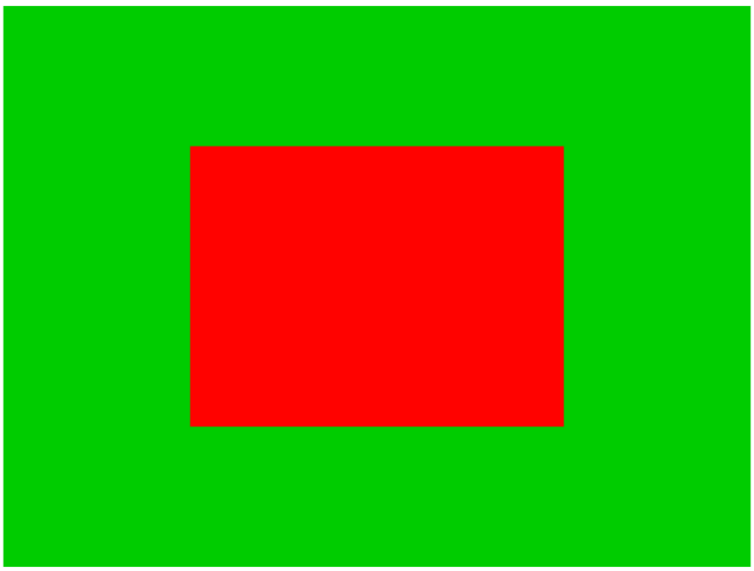


Figure 1. Canvas with Square

This simple observation leads to your next task—to allow multiple instances of `Renderable` to be visible at the same time. Each instance of `Renderable` object needs to support the ability to be drawn at different locations, with different sizes and orientations so that they do not overlap one another.

Matrices as Transform Operators

Before we begin, it is important to recognize that matrices and transformations are general topic areas in mathematics. The following discussion does not attempt to include a comprehensive coverage of these subjects. Instead, the focus is on a small collection of relevant concepts and operators from the perspective of what the game engine requires. In this way, the coverage is on how to utilize the operators and not the theories. If you are interested in the specifics of matrices and how they relate to computer graphics, please refer to the discussion in Chapter 1 where you can learn more about these topics by delving into relevant books on linear algebra and computer graphics.

A matrix is an *m* rows by *n* columns 2D array of numbers. For the purposes of this game engine, you will be working exclusively with 4×4 matrices. While a 2D game engine could get by with 3×3 matrices, a 4×4 matrix is used to support features that will be introduced in the later chapters. Among the many powerful applications, 4×4 matrices can be constructed as transform operators for vertex positions. The most important and intuitive of these operators are the translation, scaling, rotation, and identity operators.

- The translation operator `T(tx,ty)`, as illustrated in Figure 2, translates or moves a given vertex position from (x, y) to (x+tx, y+ty). Notice that `T(0,0)` does not change the value of a given vertex position and is a convenient initial value for accumulating translation operations.

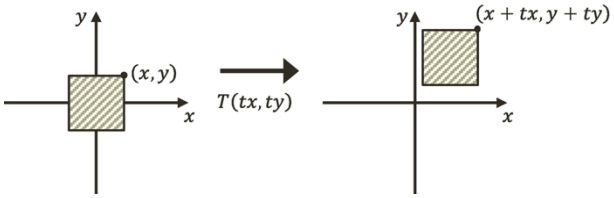


Figure 2. Translating a Square by *T(tx,ty)*

- The scaling operator `S(sx, sy)`, as illustrated by Figure 3, scales or resizes a given vertex position from (x, y) to (x×sx, y×sy). Notice that `S(1, 1)` does not change the value of a given vertex position and is a convenient initial value for accumulating scaling operations.

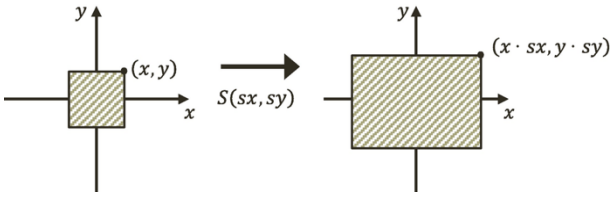


Figure 3. Scaling a Square by *S(sx,sy)*

- The rotation operator `R(θ)`, as illustrated in Figure 4, rotates a given vertex position with respect to the origin.

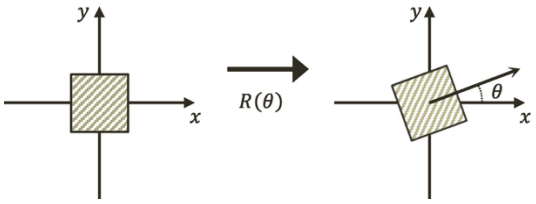


Figure 4. Scaling a Square by $R(\theta)$

In the case of rotation, `R(0)` does not change the value of a given vertex and is the convenient initial value for accumulating rotation operations. The values for θ are typically expressed in radians (and not degrees).

- The identity operator `I` does not affect a given vertex position. This operator is mostly used for initialization.

As an example, a 4×4 identity matrix looks like the following:

$$I = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Mathematically, a matrix transform operator operates on a vertex through a matrix-vector multiplication. To support this operation, a vertex position p = (x, y, z) must be represented as a 4x1 vector as follows:

$$p = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Note The z component is the third dimension, or the depth information, of a vertex position. In most cases, you should leave the z component to be 0.

For example, if position `p'` is the result of a translation operator `T` operating on the vertex position `p`, mathematically, `p'` would be computed by the following:

$$p' = T \times p = Tp$$

Concatenation of Matrix Operators

Multiple matrix operators can be concatenated, or combined, into a single operator while retaining the same transformation characteristics as the original operators. For example, you may want to apply the scaling operator `S`, followed by the rotation operator `R`, and finally the translation operator `T`, on a given vertex position, or to compute `p'` with the following:

$$p' = TRSp$$

Alternatively, you can compute a new operator `M` by concatenating all the transform operators, as follows:

$$M = TRS$$

And then operate `M` on vertex position `p`, as follows, to produce identical results:

$$p' = Mp$$

The `M` operator is a convenient and efficient way to record and reapply the results of multiple operators.

Finally, notice that when working with transformation operators, the order of operation is important. For example, a scaling operation followed by a translation operation is in general different from a translation followed by a scaling or, in general:

$$ST \neq TS$$

The glMatrix Library

The details of matrix operators and operations are nontrivial to say the least. Developing a complete matrix library is time-consuming and not the focus of this book. Fortunately, there are many well-developed and well-documented matrix libraries available in the public domain. The glMatrix library is one such example. To integrate this library into your source code structure, follow these steps:

1. Create a new folder under the `src` folder, and name the new folder `lib`.

2. Go to http://glMatrix.net , and download, unzip, and store the resulting `glMatrix.js` source file into the new `lib` folder.

3. As a library that must be accessible by both the game engine and the client game developer, you will load the source file in the main `index.html` by adding the following before the loading of `my_game.js`:

```
<!-- external library -->
<script type="text/javascript" src="src/lib/gl-matrix.js"></script>
<!-- our game -->
<script type="module" src="./src/my_game/my_game.js"></script>
```

The Matrix Transform Project

This project introduces and demonstrates how to use transformation matrices as operators to manipulate the position, size, and orientation of `Renderable` objects drawn on the canvas. In

this way, a `Renderable` can now be drawn to any location, with any size and any orientation. Figure 3-6 shows the output of running the Matrix Transform project. The source code to this project is defined in the chapter3/3.2.matrix_transform folder.

The goals of the project are as follows:

- To introduce transformation matrices as operators for drawing a `Renderable`
- To understand how to work with the transform operators to manipulate a `Renderable`

Modify the Vertex Shader to Support Transforms
As discussed, matrix transform operators operate on vertices of geometries. The vertex shader is where all vertices are passed in from the WebGL context and is the most convenient location to apply the transform operations.

You will continue working with the previous project to support the transformation operator in the vertex shader:

1. Edit `simple_vs.glsl` to declare a uniform 4×4 matrix:

Note Recall from the discussion in Chapter 2 that glsl files contain OpenGL Shading Language (GLSL) instructions that will be loaded to and executed by the GPU. You can find out more about GLSL by referring to the WebGL and OpenGL references provided at the end of Chapter 1.

```
// to transform the vertex position
uniform mat4 uModelXformMatrix;
```

Recall that the `uniform` keyword in a GLSL shader declares a variable with values that do not change for all the vertices within that shader. In this case, the `uModelXformMatrix` variable is the transform operator for all the vertices.

Note GLSL uniform variable names always begin with lowercase "u", as in `uModelXformMatrix`.

2. In the `main()` function, apply the `uModelXformMatrix` to the currently referenced vertex position:

```
gl_Position = uModelXformMatrix * vec4(aVertexPosition, 1.0);
```

Notice that the operation follows directly from the discussion on matrix transformation operators. The reason for converting `aVertexPosition` to a `vec4` is to support the matrix-vector multiplication.

With this simple modification, the vertex positions of the unit square will be operated on by the `uModelXformMatrix` operator, and thus the square can be drawn to different locations. The task now is to set up `SimpleShader` to load the appropriate transformation operator into `uModelXformMatrix`.

Modify SimpleShader to Load the Transform Operator
Follow these steps:

1. Edit simple_shader.js and add an instance variable to hold the reference to the `uModelXformMatrix` matrix in the vertex shader:

```
this.mModelMatrixRef = null;
```

2. At the end of the `SimpleShader` constructor under step E, after setting the reference to `uPixelColor`, add the following code to initialize this reference:

```
// Step E: Gets a reference to uniform variables in fragment shader
this.mPixelColorRef = gl.getUniformLocation(
                        this.mCompiledShader, "uPixelColor");
this.mModelMatrixRef = gl.getUniformLocation(
                        this.mCompiledShader, "uModelXformMatrix");
```

3. Modify the `activate()` function to receive a second parameter, and load the value to `uModelXformMatrix` via `mModelMatrixRef`:

```
activate(pixelColor, trsMatrix) {
  let gl = glSys.get();
  gl.useProgram(this.mCompiledShader);
     ... identical to previous code ...
  // load uniforms
  gl.uniform4fv(this.mPixelColorRef, pixelColor);
  gl.uniformMatrix4fv(this.mModelMatrixRef, false, trsMatrix);
}
```

The `gl.uniformMatrix4fv()` function copies the values from `trsMatrix` to the vertex shader location identified by `this.mModelMatrixRef` or the `uModelXfromMatrix` operator in the vertex shader. The name of the variable, `trsMatrix`, signifies that it should be a matrix operator containing the concatenated result of translation (`T`), rotation (`R`), and scaling (`S`) or `TRS`.

Modify Renderable Class to Set the Transform Operator

Edit `renderable.js` to modify the `draw()` function to receive and to forward a transform operator to the `mShader.activate()` function to be loaded to the GLSL shader:

```
draw(trsMatrix) {
   let gl = glSys.get();
   this.mShader.activate(this.mColor, trsMatrix);
   gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4);
}
```

In this way, when the vertices of the unit square are processed by the vertex shader, the `uModelXformMatrix` will contain the proper operator for transforming the vertices and thus drawing the square at the desired location, size, and rotation.

Testing the Transforms
Now that the game engine supports transformation, you need to modify the client code to draw with it:

1. Edit `my_game.js`; after step C, instead of activating and drawing the two squares, replace steps C1 and C2 to create a new identity transform operator, `trsMatrix`:

```
// create a new identify transform operator
let trsMatrix = mat4.create();
```

2. Compute the concatenation of matrices to a single transform operator that implements translation (`T`), rotation (`R`), and scaling (`S`) or `TRS`:

```
// Step D: compute the white square transform
mat4.translate(trsMatrix, trsMatrix, vec3.fromValues(-0.25, 0.25, 0.0));
mat4.rotateZ(trsMatrix, trsMatrix, 0.2);      // rotation is in radian
mat4.scale(trsMatrix, trsMatrix, vec3.fromValues(1.2, 1.2, 1.0));
// Step E: draw the white square with the computed transform
this.mWhiteSq.draw(trsMatrix);
```

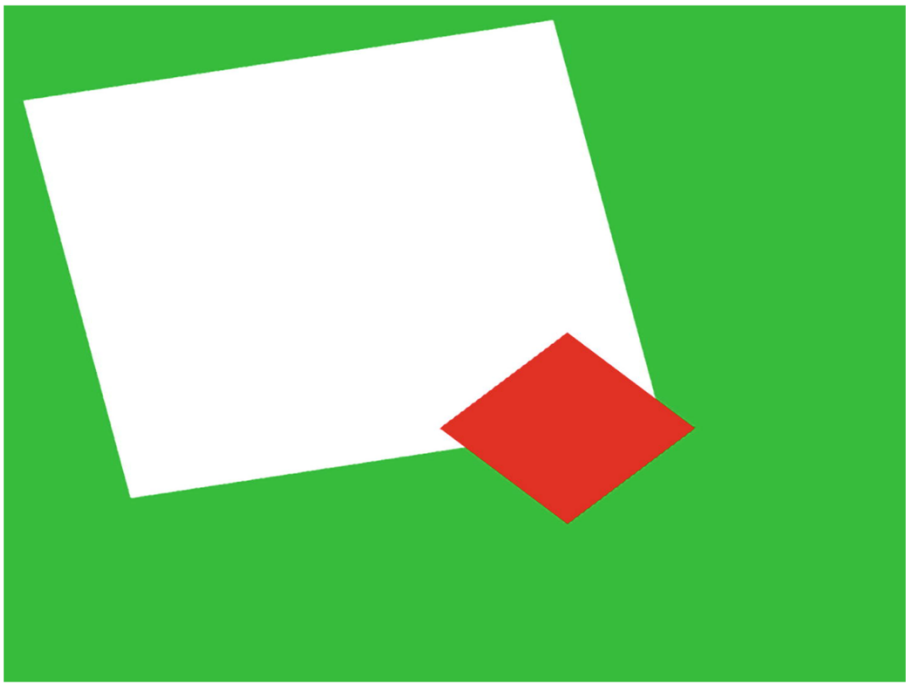
Step D concatenates `T(-0.25, 0.25)`, moving to the left and up; with `R(0.2)`, rotating clockwise by 0.2 radians; and `S(1.2, 1.2)`, increasing size by 1.2 times. The concatenation order applies the scaling operator first, followed by rotation, with translation being the last operation, or `trsMatrix=TRS`. In step E, the `Renderable` object is drawn with the `trsMatrix` operator or a 1.2×1.2 white rectangle slightly rotated and located somewhat to the upper left from the center.

3. Finally, step F defines the `trsMatrix` operator to draw a 0.4×0.4 square that is rotated by 45 degrees and located slightly toward the lower right from the center of the canvas, and step G draws the red square:

```
// Step F: compute the red square transform
mat4.identity(trsMatrix); // restart
mat4.translate(trsMatrix, trsMatrix, vec3.fromValues(0.25, -0.25, 0.0));
mat4.rotateZ(trsMatrix, trsMatrix, -0.785);   // about -45-degrees
mat4.scale(trsMatrix, trsMatrix, vec3.fromValues(0.4, 0.4, 1.0));
// Step G: draw the red square with the computed transform
this.mRedSq.draw(trsMatrix);
```

Observations

Run the project, and you should see the corresponding white and red rectangles drawn on the canvas. You can gain some intuition of the operators by changing the values; for example, move and scale the squares to different locations with different sizes. You can try changing the order of concatenation by moving the corresponding line of code; for example, move `mat4.scale()` to before `mat4.translate()`. You will notice that, in general, the transformed results do not correspond to your intuition. In this book, you will always apply the transformation operators in the fixed `TRS` order. This ordering of transformation operators corresponds to typical human intuition. The `TRS` operation order is followed by most, if not all, graphical APIs and applications that support transformation operations.



Now that you understand how to work with the matrix transformation operators, it is time to abstract them and hide their details.

Encapsulating the Transform Operator

In the previous project, the transformation operators were computed directly based on the matrices. While the results were important, the computation involves distracting details and repetitive code. This project guides you to follow good coding practices to encapsulate the transformation operators by hiding the detailed computations with a class. In this way, you can maintain the modularity and accessibility of the game engine by supporting further expansion while maintaining programmability.

The Transform Objects Project

This project defines the `Transform` class to provide a logical interface for manipulating and hiding the details of working with the matrix transformation operators.

The goals of the project are as follows:

- To create the `Transform` class to encapsulate the matrix transformation functionality
- To integrate the `Transform` class into the game engine
- To demonstrate how to work with `Transform` objects

The Transform Class

Continue working with the previous project:

1. Define the `Transform` class in the game engine by creating a new source code file in the `src/engine` folder and name the file `transform.js`.

2. Define the constructor to initialize instance variables that correspond to the operators: `mPosition` for translation, `mScale` for scaling, and `mRotationInRad` for rotation.

```
class Transform {
  constructor() {
    this.mPosition = vec2.fromValues(0, 0);  // translation
    this.mScale = vec2.fromValues(1, 1);     // width (x), height (y)
    this.mRotationInRad = 0.0;               // in radians!
  }
  ... implementation to follow ...
}
```

3. Add getters and setters for the values of each operator:

```
// Position getters and setters
setPosition(xPos, yPos) { this.setXPos(xPos); this.setYPos(yPos); }
getPosition() { return this.mPosition; }
// ... additional get and set functions for position not shown

// Size setters and getters
setSize(width, height) {
  this.setWidth(width);
```

```
    this.setHeight(height);
  }

  getSize() { return this.mScale; }
  // ... additional get and set functions for size not shown

  // Rotation getters and setters
  setRotationInRad(rotationInRadians) {
    this.mRotationInRad = rotationInRadians;
    while (this.mRotationInRad > (2 * Math.PI)) {
     this.mRotationInRad -= (2 * Math.PI);
    }
  }
  setRotationInDegree(rotationInDegree) {
    this.setRotationInRad(rotationInDegree * Math.PI / 180.0);
  }
  // ... additional get and set functions for rotation not shown
```

4. Define the `getTRSMatrix()` function to compute and return the concatenated transform operator, `TRS`:

```
  getTRSMatrix() {
    // Creates a blank identity matrix
    let matrix = mat4.create();
    // Step A: compute translation, for now z is always at 0.0
    mat4.translate(matrix, matrix,
                   vec3.fromValues(this.getXPos(), this.getYPos(), 0.0));
    // Step B: concatenate with rotation.
    mat4.rotateZ(matrix, matrix, this.getRotationInRad());
    // Step C: concatenate with scaling
    mat4.scale(matrix, matrix,
               vec3.fromValues(this.getWidth(), this.getHeight(), 1.0));
    return matrix;
  }
```

This code is similar to steps D and F in `my_game.js` from the previous project. The concatenated operator `TRS` performs scaling first, followed by rotation, and lastly by translation.

5. Finally, remember to export the newly defined `Transform` class:

```
  export default Transform;
```

The Transformable Renderable Class

By integrating the `Transform` class, a `Renderable` object can now have a position, size (scale), and orientation (rotation). This integration can be easily accomplished through the following steps:

1. Edit `renderable.js` and add a new instance variable to reference a `Transform` object in the constructor:

```
this.mXform = new Transform();     // transform operator for the object
```

2. Define an accessor for the transform operator:

```
getXform() { return this.mXform; }
```

3. Modify the `draw()` function to pass the `trsMatrix` operator of the `mXform` object to activate the shader before drawing the unit square:

```
draw() {
  let gl = glSys.get();
  this.mShader.activate(this.mColor, this.mXform.getTRSMatrix());
  gl.drawArrays(gl.TRIANGLE_STRIP, 0, 4);
}
```

With this simple modification, `Renderable` objects will be drawn with characteristics defined by the values of its own transformation operators.

Modify the Engine Access File to Export Transform
It is important to maintain the engine access file, index.js, up to date such that the newly defined Transform class can be accessed by the game developer:

1. Edit `index.js`; import from the newly define `transform.js` file:

```
// general utilities
import Transform from "./transform.js";
import Renderable from "./renderable.js";
```

2. Export Transform for client's access:

```
export default {
  // Util classes
  Transform, Renderable,
```

```
    // functions
    init, clearCanvas
}
```

Modify Drawing to Support Transform Object
To test the Transform and the improved `Renderable` classes, the `MyGame` constructor can be modified to set the transform operators in each of the `Renderable` objects accordingly:

```
// Step D: sets the white Renderable object's transform
this.mWhiteSq.getXform().setPosition(-0.25, 0.25);
this.mWhiteSq.getXform().setRotationInRad(0.2); // In Radians
this.mWhiteSq.getXform().setSize(1.2, 1.2);
// Step E: draws the white square (transform behavior in the object)
this.mWhiteSq.draw();
// Step F: sets the red square transform
this.mRedSq.getXform().setXPos(0.25); // alternative to setPosition
this.mRedSq.getXform().setYPos(-0.25);// setX/Y separately
this.mRedSq.getXform().setRotationInDegree(45);  // this is in Degree
this.mRedSq.getXform().setWidth(0.4); // alternative to setSize
this.mRedSq.getXform().setHeight(0.4);// set width/height separately
// Step G: draw the red square (transform in the object)
this.mRedSq.draw();
```

Run the project to observe identical output as from the previous project. You can now create and draw a `Renderable` at any location in the canvas, and the transform operator has now been properly encapsulated.

The Camera Transform and Viewports
When designing and building a video game, the game designers and programmers must be able to focus on the intrinsic logic and presentation. To facilitate these aspects, it is important that the designers and programmers can formulate solutions in a convenient dimension and space.

For example, continuing with the soccer game idea, consider the task of creating a soccer field. How big is the field? What is the unit of measurement? In general, when building a game world, it is often easier to design a solution by referring to the real world. In the real world, soccer fields are around 100 meters long. However, in the game or graphics world, units are arbitrary. So, a simple solution may be to create a field that is 100 units in meters and a coordinate space where the origin is located at the center of the soccer field. In this way, opposing sides of the fields can simply be determined by the sign of the x value, and drawing a player at location (0, 1) would mean drawing the player 1 meter to the right from the center of the soccer field.

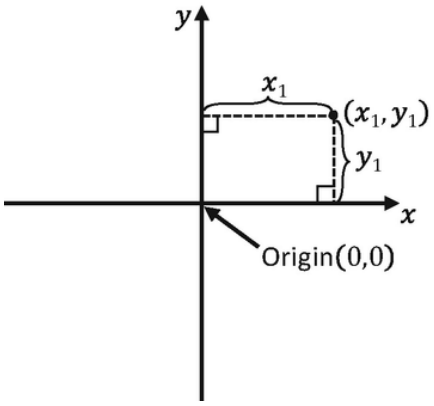
A contrasting example would be when building a chess-like board game. It may be more convenient to design the solution based on a unitless n×n grid with the origin located at the lower-left corner of the board. In this scenario, drawing a piece at location (0, 1) would mean drawing the piece at the location one cell or unit toward the right from the lower-left corner of

the board. As will be discussed, the ability to define specific coordinate systems is often accomplished by computing and working with a matrix representing the view from a camera.

In all cases, to support a proper presentation of the game, it is important to allow the programmer to control the drawing of the contents to any location on the canvas. For example, you may want to draw the soccer field and players to one subregion and draw a mini-map into another subregion. These axis-aligned rectangular drawing areas or subregions of the canvas are referred to as viewports.

In this section, you will learn about coordinate systems and how to use the matrix transformation as a tool to define a drawing area that conforms to the fixed ±1 drawing range of the WebGL.

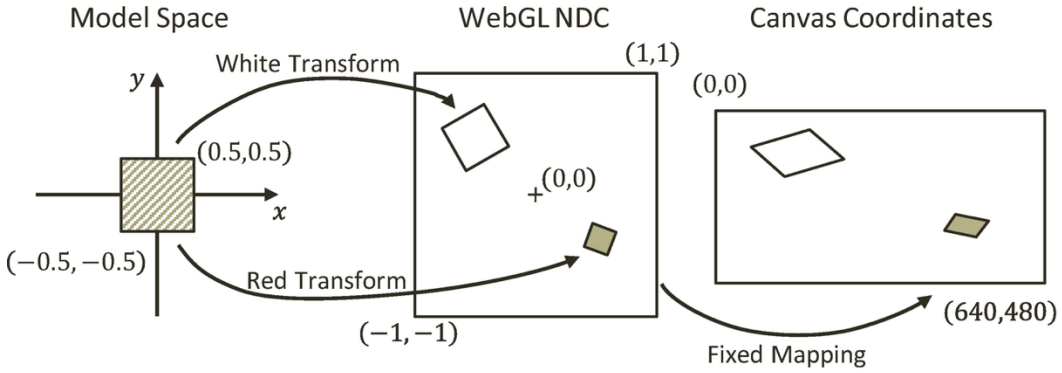
Coordinate Systems and Transformations
A 2D coordinate system uniquely identifies every position on a 2D plane. All projects in this book follow the Cartesian coordinate system where positions are defined according to perpendicular distances from a reference point known as the *origin*, as illustrated below. The perpendicular directions for measuring the distances are known as the *major axes*. In 2D space, these are the familiar x and y axes.



Modeling and Normalized Device Coordinate Systems
So far in this book, you have experience with two distinct coordinate systems. The first is the coordinate system that defines the vertices for the 1×1 square in the vertex buffer. This is referred to as the Modeling Coordinate System, which defines the Model Space. The Model Space is unique for each geometric object, as in the case of the unit square. The Model Space is defined to describe the geometry of a single model. The second coordinate system that you have worked with is the one that WebGL draws to, where the x-/y-axis ranges are bounded to ±1.0. This is known as the Normalized Device Coordinate (NDC) System. As you have experienced, WebGL always draws to the NDC space and that the contents in the ±1.0 range cover all the pixels in the canvas.

The Modeling transform, typically defined by a matrix transformation operator, is the operation that transforms geometries from its Model Space into another coordinate space that is

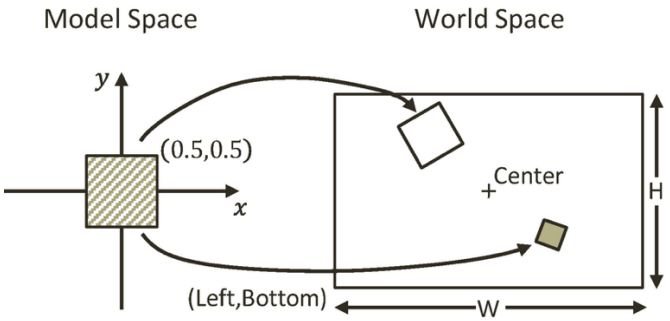
convenient for drawing. In the previous project, the `uModelXformMatrix` variable in `simple_vs.glsl` is the Modeling transform. As illustrated below, in that case, the Modeling transform transformed the unit square into the WebGL's NDC space. The rightmost arrow annotated with the Fixed Mapping label in the figure that points from WebGL NDC to Canvas Coordinates signifies that WebGL always displays the entire content of the NDC space in the canvas.



The World Coordinate System

Although it is possible to draw to any location with the Modeling transform, the disproportional scaling that draws squares as rectangles is still a problem. In addition, the fixed -1.0 and 1.0 NDC space is not a convenient coordinate space for designing games. The World Coordinate (WC) System describes a convenient World Space that resolves these issues. For convenience and readability, in the rest of this book, WC will also be used to refer to the World Space that is defined by a specific World Coordinate System.

As illustrated below, with a WC instead of the fixed NDC space, Modeling transforms can transform models into a convenient coordinate system that lends itself to game designs. For the soccer game example, the World Space dimension can be the size of the soccer field. As in any Cartesian coordinate system, the WC system is defined by a reference position and its width and height. The reference position can either be the lower-left corner or the center of the WC.



The WC is a convenient coordinate system for designing games. However, it is not the space that WebGL draws to. For this reason, it is important to transform from WC to NDC. In this book, this transform is referred to as the Camera transform. To accomplish this transform, you will have to

construct an operator to align WC center with that of the NDC (the origin) and then to scale the WC WxH dimension to match the NDC width and height. Note that the NDC space has a constant range of -1 to +1 and thus a fixed dimension of 2x2. In this way, the Camera transform is simply a translation followed by a scaling operation:

$$M = S\left(\frac{2}{W}, \frac{2}{H}\right) T(-center.x, -center.y)$$

In this case, `(center.x, center.y)` and `WxH` are the center and the dimension of the WC system.

The Viewport

A viewport is an area to be drawn to. As you have experienced, by default, WebGL defines the entire canvas to be the viewport for drawing. Conveniently, WebGL provides a function to override this default behavior:

```
gl.viewport(
      x,    // x position of bottom-left corner of the area to be drawn
      y,    // y position of bottom-left corner of the area to be drawn
      width, // width of the area to be drawn
      height // height of the area to be drawn
);
```

The `gl.viewport()` function defines a viewport for all subsequent drawings. Figure 3-11 illustrates the Camera transform and drawing with a viewport.