ECE 322
Lab Report 4

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1 Introduction

The purpose of this lab was to serve as an introduction to white-box testing. The goal was to become familiar with the JUnit testing library in Java, as well as using an orthogonal table to come up with test cases for pairwise testing, and using a tool named PICT (Pairwise Independent Combinatorial Tool) to generate pairwise tests. White-box testing, in contrast to Black-Box testing focuses on testing the internal parts of an application. That is, instead of having only an outsider view of the application, we use the insight we know about the application from knowing its source code and implementation details to come up with tests to test the program for failures. We also look at pairwise testing, which is an efficient way to come up with a set of test cases that covers all possible combinations of pairs of inputs. In the first part, a program written in Java was tested, named Bisect. This program implements the well-known bisection algorithm in mathematics to find the root of a polynomial in an interval where the polynomial crosses $x = 0$. The source code was analyzed, and test cases were generated test for failures in the program. Not only were the test cases testing the functionality of the application, but we also had to ensure that together, all lines of code in the program were executed, and all branches were taken. Additionally, a control flow graph was generated. For the second part of this lab, a conceptual exercise was done to think about and discuss the benefits of pairwise testing versus exhaustive testing, and the effectiveness of the tests generated using this method. We also compared the tests generated by the PICT tool versus tests made using a standard orthogonal array.

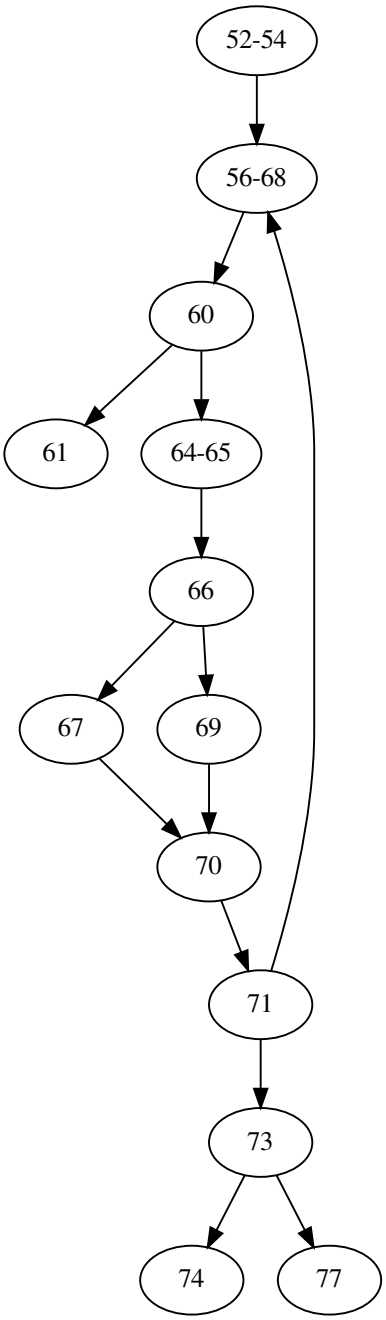
2 Task 1

For task one in this lab, the Bisect application was tested using White box testing methods. Bisect is a program written in Java, which uses the well-known bisection algorithm in mathematics to attempt to find the root of any polynomial in a given interval that crosses $x = 0$ somewhere. That is, wherever

the polynomial intersects $x = 0$. The algorithm which the program implements is outlined as follows:

1. Calculate c, the midpoint of the interval: $c = \frac{a+b}{2}$
2. Calculate the polynomial's value at $f(c)$
3. If $|f(c)|$ is within the tolerance, stop
4. Check the sign of $f(c)$ and replace either $(a, f(a))$ or $(b, f(b))$ with $(c, f(c))$ such that the interval crosses $x = 0$ somewhere and repeat until step 3 quits

Since this is white box testing, we have access to the source code for this application. By inspecting the source code, the following control flow graph was generated for the application. The numbers in each node represent the line numbers in the source code in **Bisect.java**.


52-54
56-68
60
61
64-65
66
67
69
70
71
73
74
77

By inspecting the source code and understanding the bisection algorithm, some JUnit test cases were generated. These test cases can be found in Appendix **??**. A summary of these test cases is outlined in the table below.

Test Id	Description	tolerance	max iterations	polynomial	x_1	x_2	Expected	Actual
1	Exception is thrown when both $f(x_1)$ and $f(x_2)$ are > 0	0.000001	50	$x^2 - 1$	-5	5	Exception	Exception
2	Exception is thrown when maximum iterations are exceeded	0.000001	1	$x + 100$	-150	1000000000	Exception	Exception
3	Test constructor with tolerance	50.0	50	x	-10	10	0	0
4	Test constructor with tolerance and max iterations	0	50	x	-10	10	0	0
5	Max iterations getter	0.000001	500	x	n/a	n/a	500	500
6	Max iterations setter	0.000001	500	x	n/a	n/a	500	500
7	Tolerance getter	0.0	50	x	n/a	n/a	0.0	0.0
8	Tolerance setter	0.0	50	x	n/a	n/a	0.0	0.0
9	Normal test case, make sure that $f(result) \leq result$, and it iterates more than once	0.000001	50	$x^2 - 1$	-1.5	0.5	-1	-1

While code coverage is a useful metric for determining the quality of tests, it should not be the only factor in determining the quality of the tests. After all, it is possible to have all tests cover all lines and branches, but the tests may not be checking for the correctness in execution of these statements and branching conditions. What is useful however, is knowing which lines of the code have been executed in the tests. That way, if a line is missed for example, code coverage criterion will bring to light that fact that the line of code was not covered. Furthermore, branch coverage will also ensure that all branches have been executed in the tests. In short, coverage criterion is effective for letting us know when a part of the code *for sure* is not being tested. It does not however, guarantee that the correctness of the covered statements and branches.

Based solely on the coverage criteria, it would be in my opinion foolish, or at best naive to be completely confident in the application being bug-free. Having well-thought-out tests that adequately cover the functionality of the programs *in addition to* the code coverage criterion, however, does increase my confidence in the program working. Tests that are written such that they only cover the code coverage criterion will not adequately cover the correctly. The tests have to

be made with the knowledge of how the Bisection algorithm works, and testing that the program computes the result as expected. With the test cases made in this lab, (available in Appendix **??**), I am fairly confident that the portion of the program that does the Bisection algorithm works correctly, since they were crafted with the knowledge of how the Bisection algorithm works, and therefore test that the functionality of the algorithm.

In general, the number of paths available to test is a number between $n+1 \leq x \leq 2^n$, where n is the number of branches. This depends on when the branches merge. Additionally, for this application, there is a branch decision on every loop iteration. So, the number of test cases depends on the number of maximum iterations. Even with the default value of 50 iterations, we can see how quickly the number of tests needed for path coverage can blow up exponentially to ridiculous proportions, which is why path coverage is not realistic.

3 Task 2

For the second part of the lab, we are to assume that we have a system with three independent variables: A, B, C. Each variable has three possible values: 0, 1, 2. There is no actual testing for this portion, it is a conceptual exercise.

In total, there are $3 \times 3 \times 3 = 27$ test cases if we were to do combinatorial testing. We are looking for a standard orthogonal array that can fit 3^3. From `http://neilsloane.com/oadir/`, we find that the $L_9(3^4)$ standard orthogonal array works. Below is the set of test cases using the orthogonal array mentioned above:

```
0       0       0       0
0       1       1       2
0       2       2       1
1       0       1       1
1       1       2       0
1       2       0       2
2       0       2       2
2       1       0       1
2       2       1       0
```

The PICT program (`https://github.com/microsoft/pict`) was used to generate test cases with the following input:

```
A: 0, 1, 2
B: 0, 1, 2
C: 0, 1, 2
```

It should be noted that strangely, there seems to be different outputs depending on the operating system that pict is run on.

On GNU/Linux systems, the output is as follows:

```
A       B       C
0       0       0
0       2       1
2       0       2
1       0       1
2       1       0
1       1       2
0       1       1
1       2       0
0       2       2
2       2       1
```

On Windows, the output is as follows:

```
A       B       C
1       2       0
2       0       2
0       1       0
2       2       1
0       0       1
1       1       2
2       0       0
0       2       2
1       0       1
2       1       1
```

On macOS, the output is as follows:

```
A       B       C
0       2       2
2       2       1
0       0       0
2       1       0
2       0       2
1       2       0
0       1       1
1       1       2
1       0       1
```

What is strange is that on the Windows and macOS systems, 10 test cases are generated, while on GNU/Linux, 11 test cases are generated.

Given the inconsistent outputs of the pict tool depending on the operating system that the program is run on, I am not sure about the effectiveness of the tool for test case generation. Ideally, the test cases generated should be consistent, since this they are not supposed to be chosen randomly. If the program worked consistently, however, it would be quite effective since not much effort would be required to come up with the test cases, and we have the guarantee that every pair of inputs is tested. Compared to the orthogonal array, the

pict tool generated more test cases, which is another consideration to take into account.

Pairwise testing is fairly useful, especially when you consider it versus combinatorial testing. In this toy example, the number of test cases was not reduced that much, (27 for combinatorial testing, versus 9 with an orthogonal table), but one can imagine the reduction in test cases when there are more inputs, and more possible values that these inputs can take on. Compared with random combinations, pairwise testing gives us the guarantee that we are testing every single pair of input factors, whereas random combinations does not have this guarantee, and there are far more combinations to choose from. However, random combinations can by chance reveal errors that pairwise testing would not catch.

Pairwise testing catches errors where two inputs interact with each other. It does not take into account the effect that multiple inputs might have together. For example, imagine an application that requires three inputs to be in a certain state before something gets activated. Using pairwise testing there is a possibility that we would miss testing the part of the app, where three inputs are in the state for something to happen, since the pairwise tests would only focus on the combination of pairs of the inputs. In this way, core functionality of the application can be missed in testing. Furthermore, with pairwise testing it is possible to miss the more probable combinations when selecting the test data. However, given the reduction in the number of test cases versus exhaustive testing, not to mention the cost of running so many tests, these weaknesses may be justifiable to some testers, given that pairwise testing usually results yields higher defect detection rates, increases the test coverage, all while using significantly less test cases. As mentioned above, to cover all possible inputs for the application in this example, a total of 27 test cases are required.

4 Conclusion

In this lab, we were introduced to the white-box testing strategy. There was a focus on control flow testing, and coverage criterion: Statement coverage, branch coverage, condition coverage, and path coverage. A control flow graph was generated, and test cases were made knowing the implementation of the program, and by inspecting to source code. Knowing the implementation details of the program allowed for the creation of test cases that not only check for correctness of the implementation of the algorithm, but also that all lines and branches in the code were covered by the tests. Statement and branch coverage on their own do not indicate good tests, but they can at a glance tell us which parts of an application for sure have not been tested yet. In this part of the lab, we also discovered the infeasability of path coverage, due to a while loop causing the number of potential paths taken to increase exponentially. In the second part of the lab, the focus was on pairwise testing, where we analyzed a hypothetical testing scenario and used a standard orthogonal array to generate test cases, and contrasted that with using a tool made my Microsoft named PICT which

automatically generates test cases, and compared and contrasted these methods versus exhaustive testing. In general, it seems like pairwise testing is great for reducing the number of test cases, while still keeping detection rate of failures high, but it also has some weaknesses, like when more than two inputs have some important relation in the application, when pairwise testing by definition only looks at the relationships between each pair of inputs.

A Big Bang Testing Strategy

A.1 Module A

```
1  package bigbang;
2
3  import data.Entry;
4  import modules.*;
5  import org.junit.jupiter.api.BeforeEach;
6  import org.junit.jupiter.api.Test;
7  import org.mockito.Mockito;
8
9  import java.io.ByteArrayOutputStream;
10 import java.io.PrintStream;
11 import java.util.ArrayList;
12
13 import static org.junit.jupiter.api.Assertions.assertEquals;
14 import static org.junit.jupiter.api.Assertions.assertThrows;
15 import static org.mockito.ArgumentMatchers.*;
16 import static org.mockito.Mockito.*;
17
18
19 public class TestA {
20
21     ModuleA ma;
22     ModuleB mb;
23     ModuleC mc;
24     ModuleD md;
25     ModuleE me;
26     final static String TEST_FILENAME = "testFileName";
27
28     ByteArrayOutputStream stdout;
29
30     @BeforeEach
31     public void setUp(){
32         mb = Mockito.mock(ModuleB.class);
33         mc = Mockito.mock(ModuleC.class);
34         md = Mockito.mock(ModuleD.class);
35         me = Mockito.mock(ModuleE.class);
36
37         ma = new ModuleA(mb, mc, md, me);
38
39         newStdout();
40     }
41
42     public void newStdout(){
```

```
43          stdout = new ByteArrayOutputStream();
44          ma.setOutputStream(new PrintStream(stdout));
45      }
46
47      @Test
48      public void testHelp() throws ModuleE.DataBaseExitException {
49          ma.run(new String[]{"help"});
50
51          final String help = "Available Commands: \n" +
52                  "load <filepath>\n" +
53                  "add <name> <number>\n" +
54                  "update <index> <name> <number>\n" +
55                  "delete <index>\n" +
56                  "sort\n" +
57                  "exit";
58
59          assertEquals(help + "\n", stdout.toString());
60
61      }
62
63      public void load() throws ModuleE.DataBaseExitException {
64          Mockito.when(md.insertData(any(), anyString(),
            ↪  anyString(), anyString())).thenReturn(new
            ↪  ArrayList<Entry>());
65          ma.run(new String[]{"load", TEST_FILENAME});
66      }
67
68      @Test
69      public void testLoad() throws ModuleE.DataBaseExitException {
70          load();
71          verify(mb, times(1)).loadFile(anyString());
72      }
73
74      @Test
75      public void testLoadNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
76              ma.run(new String[]{"load"});
77              assertEquals("Malformed command!\n",
                ↪  stdout.toString());
78              verify(mb, never()).loadFile(anyString());
79      }
80
81      @Test
82      public void testLoadBReturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
83          Mockito.when(mb.loadFile(anyString())).thenReturn(null);
```

```
84          ma.run(new String[]{"load", TEST_FILENAME});
85          verify(mb, times(1)).loadFile(anyString());
86      }
87
88      @Test
89      public void testAddNoData() throws
        ↪  ModuleE.DataBaseExitException {
90          ma.run(new String[]{"add", "name", "number"});
91          assertEquals("No file loaded!\n", stdout.toString());
92          verify(md, never()).insertData(any(), anyString(),
            ↪  anyString(), anyString());
93      }
94
95      @Test
96      public void testAdd() throws ModuleE.DataBaseExitException {
97          Mockito.when(md.insertData(any(), anyString(),
            ↪  anyString(), anyString())).thenReturn(new
            ↪  ArrayList<Entry>());
98          ma.run(new String[]{"load", TEST_FILENAME});
99          ma.run(new String[]{"add", "name", "number"});
100         verify(md, times(1)).insertData(any(), anyString(),
            ↪  anyString(), anyString());
101     }
102
103     @Test
104     public void testAddDreturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
105         Mockito.when(md.insertData(any(), anyString(),
            ↪  anyString(), anyString())).thenReturn(null);
106         ma.run(new String[]{"load", TEST_FILENAME});
107         ma.run(new String[]{"add", "name", "number"});
108         verify(md, times(1)).insertData(any(), anyString(),
            ↪  anyString(), anyString());
109     }
110
111     @Test
112     public void testAddNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
113         ma.run(new String[]{"load", TEST_FILENAME});
114         ma.run(new String[]{"add"});
115         assertEquals("Malformed command!\n", stdout.toString());
116         verify(md, never()).insertData(any(), anyString(),
            ↪  anyString(), anyString());
117     }
118
119     @Test
```

```
120     public void testSort() throws ModuleE.DataBaseExitException {
121         ma.run(new String[]{"load", TEST_FILENAME});
122         ma.run(new String[]{"sort"});
123         verify(mc, times(1)).sortData(any());
124     }
125 
126     @Test
127     public void testSortNoData() throws
        ↪  ModuleE.DataBaseExitException {
128         ma.run(new String[]{"sort"});
129         assertEquals("No file loaded!\n", stdout.toString());
130         verify(mc, never()).sortData(any());
131     }
132 
133     @Test
134     public void testSortCReturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
135         Mockito.when(mc.sortData(any())).thenReturn(null);
136         ma.run(new String[]{"load", TEST_FILENAME});
137         ma.run(new String[]{"sort"});
138         verify(mc, times(1)).sortData(any());
139     }
140 
141     @Test
142     public void testUpdate() throws ModuleE.DataBaseExitException
        ↪  {
143         ma.run(new String[]{"load", TEST_FILENAME});
144         ma.run(new String[]{"update", "1", "2", "3"});
145         verify(md, times(1)).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
146     }
147 
148     @Test
149     public void testUpdateInvalidArguments() throws
        ↪  ModuleE.DataBaseExitException {
150         ma.run(new String[]{"load", TEST_FILENAME});
151         ma.run(new String[]{"update", "arg1", "arg2", "arg3"});
152         verify(md, never()).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
153     }
154 
155 
156     @Test
157     public void testUpdateNoData() throws
        ↪  ModuleE.DataBaseExitException {
158         ma.run(new String[]{"update", "1", "2", "3"});
```

```
159             assertEquals("No file loaded!\n", stdout.toString());
160             verify(md, never()).updateData(any(), anyInt(),
                ↪  anyString(), anyString(), anyString());
161         }
162
163         @Test
164         public void testUpdateCReturnsNull() throws
                ↪  ModuleE.DataBaseExitException {
165             Mockito.when(md.updateData(any(), anyInt(), anyString(),
                ↪  anyString(), anyString())).thenReturn(null);
166             ma.run(new String[]{"load", TEST_FILENAME});
167             ma.run(new String[]{"update", "1", "2", "3"});
168             verify(md, times(1)).updateData(any(), anyInt(),
                ↪  anyString(), anyString(), anyString());
169         }
170
171         @Test
172         public void testUpdateNoArgument() throws
                ↪  ModuleE.DataBaseExitException {
173             ma.run(new String[]{"load", TEST_FILENAME});
174             ma.run(new String[]{"update"});
175             assertEquals("Malformed command!\n", stdout.toString());
176             verify(md, never()).updateData(any(), anyInt(),
                ↪  anyString(), anyString(), anyString());
177         }
178
179         @Test
180         public void testDelete() throws ModuleE.DataBaseExitException
                ↪  {
181             ma.run(new String[]{"load", TEST_FILENAME});
182             ma.run(new String[]{"delete", "1"});
183             verify(md, times(1)).deleteData(any(), anyInt(),
                ↪  anyString());
184         }
185
186         @Test
187         public void testDeleteInvalidArguments() throws
                ↪  ModuleE.DataBaseExitException {
188             ma.run(new String[]{"load", TEST_FILENAME});
189             ma.run(new String[]{"delete", "arg1"});
190             verify(md, never()).deleteData(any(), anyInt(),
                ↪  anyString());
191         }
192
193         @Test
```

```
194     public void testDeleteNoData() throws
        ↪  ModuleE.DataBaseExitException {
195         ma.run(new String[]{"delete"});
196         assertEquals("No file loaded!\n", stdout.toString());
197         verify(md, never()).deleteData(any(), anyInt(),
            ↪  anyString());
198     }
199
200     @Test
201     public void testDeleteDReturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
202         Mockito.when(md.deleteData(any(), anyInt(),
            ↪  anyString())).thenReturn(null);
203         ma.run(new String[]{"load", TEST_FILENAME});
204         ma.run(new String[]{"delete", "1"});
205         verify(md, times(1)).deleteData(any(), anyInt(),
            ↪  anyString());
206     }
207
208     @Test
209     public void testDeleteNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
210         ma.run(new String[]{"load", TEST_FILENAME});
211         ma.run(new String[]{"delete"});
212         assertEquals("Malformed command!\n", stdout.toString());
213         verify(md, never()).deleteData(any(), anyInt(),
            ↪  anyString());
214     }
215
216     @Test
217     public void testExit() throws ModuleE.DataBaseExitException {
218
            ↪  Mockito.doThrow(ModuleE.DataBaseExitException.class).when(me).exitProgram();
219         assertThrows(ModuleE.DataBaseExitException.class, ()
            ↪  ->ma.run(new String[]{"exit"}));
220         // line 147 does not get covered, because the program
            ↪  exits
221     }
222
223
224 }
```

A.2 Module B

```
1 package bigbang;
2
```

```
3  import TestUtil.TestUtil;
4  import modules.ModuleB;
5  import modules.ModuleF;
6  import org.junit.jupiter.api.AfterEach;
7  import org.junit.jupiter.api.BeforeEach;
8  import org.junit.jupiter.api.Test;
9
10 import java.io.File;
11 import java.io.IOException;
12 import java.nio.file.Files;
13 import data.Entry;
14 import java.nio.file.Paths;
15 import java.util.ArrayList;
16
17 import static org.junit.jupiter.api.Assertions.assertArrayEquals;
18 import static org.junit.jupiter.api.Assertions.assertEquals;
19 import static org.mockito.Mockito.mock;
20
21 // IO Exception catching is not tested
22 // Explain in the report that it's just calling a library
   ↪  function
23 // Also, the scenario was never encountered e.g. reading
   ↪  /etc/shadow
24
25 public class TestB {
26
27     ModuleB mb;
28     ModuleF mf;
29     final static String TEST_FILENAME = "BTEST_FILE";
30     static File f;
31
32     @BeforeEach
33     public void setUp() throws IOException {
34         mf = mock(ModuleF.class);
35         mb = new ModuleB(mf);
36
37         f = new File(TEST_FILENAME);
38         f.createNewFile();
39         Files.writeString(Paths.get(TEST_FILENAME), """
40 This
41 is,some
42 test
43 data""");
44     }
45
46     @AfterEach
```

```
47      public void tearDown(){
48          f.delete();
49      }
50
51      @Test
52      public void loadFileTestValidFile() {
53         ArrayList<Entry> ret =  mb.loadFile(TEST_FILENAME);
54
55         ArrayList<Entry> expected = new ArrayList<>() {{
56             add(new Entry("is", "some"));
57         }};
58
59         TestUtil.compareArrayOfEntries(expected, ret);
60      }
61
62      @Test
63      public void loadFileTestInValidFile()  {
64         mb.loadFile("/");
65      }
66
67      @Test
68      public void loadFileTestFileNotFound(){
69          mb.loadFile("");
70      }
71
72      @Test
73      public void setFTest(){
74          ModuleF newF = mock(ModuleF.class);
75          mb.setF(newF);
76      }
77  }
```

A.3 Module C

```
1   package bigbang;
2
3   import TestUtil.TestUtil;
4   import data.Entry;
5   import modules.ModuleC;
6   import modules.ModuleF;
7   import org.junit.jupiter.api.BeforeEach;
8   import org.junit.jupiter.api.Test;
9
10  import java.util.ArrayList;
11
12  import static org.mockito.Mockito.mock;
```

```
13
14  public class TestC {
15
16      ModuleF mf;
17      ModuleC mc;
18
19      @BeforeEach
20      public void setUp(){
21          mf = mock(ModuleF.class);
22          mc = new ModuleC(mf);
23      }
24
25      @Test
26      public void sortDataTest(){
27
28          final String TEST_NAME = "testName";
29          final String TEST_NUMBER = "testNumber";
30
31          ArrayList<Entry> unsorted = new ArrayList<>() {{
32              add(new Entry("ddd", "aaa"));
33              add(new Entry("bbb", "bbb"));
34              add(new Entry("ccc", "ccc"));
35              add(new Entry("aaa", "aaa"));
36              add(new Entry("ccc", "aaa"));
37              add(new Entry("bbb", "aaa"));
38          }};
39
40          ArrayList<Entry> sorted = new ArrayList<>() {{
41              add(new Entry("aaa", "aaa"));
42              add(new Entry("bbb", "aaa"));
43              add(new Entry("bbb", "bbb"));
44              add(new Entry("ccc", "aaa"));
45              add(new Entry("ccc", "ccc"));
46              add(new Entry("ddd", "aaa"));
47          }};
48          ArrayList<Entry> ret = mc.sortData(unsorted);
49
50          TestUtil.compareArrayOfEntries(sorted, ret);
51      }
52
53      @Test
54      public void setFTest(){
55          ModuleF newF = mock(ModuleF.class);
56          mc.setF(newF);
57      }
58
```

```
59      // to cover line 28 in ModuleC
60      @Test
61      public void sortFourElementsTest(){
62          ArrayList<Entry> unsorted = new ArrayList<>() {{
63              add(new Entry("ccc", "ccc"));
64              add(new Entry("aaa", "aaa"));
65              add(new Entry("bbb", "ddd"));
66              add(new Entry("bbb", "aaa"));
67          }};
68
69          ArrayList<Entry> sorted = new ArrayList<>() {{
70              add(new Entry("aaa", "aaa"));
71              add(new Entry("bbb", "aaa"));
72              add(new Entry("bbb", "ddd"));
73              add(new Entry("ccc", "ccc"));
74          }};
75
76          ArrayList<Entry> ret = mc.sortData(unsorted);
77
78          TestUtil.compareArrayOfEntries(sorted, ret);
79      }
80
81  }
```

A.4 Module D

```
1   package bigbang;
2
3   import TestUtil.TestUtil;
4   import data.Entry;
5   import modules.ModuleD;
6   import modules.ModuleF;
7   import modules.ModuleG;
8   import org.junit.jupiter.api.*;
9
10  import java.util.ArrayList;
11
12  import static org.mockito.Mockito.*;
13
14
15  public class TestD {
16
17      ModuleF mf;
18      ModuleG mg;
19      ModuleD md;
20
```

```
21      final static String TEST_NAME = "testName";
22      final static String TEST_NUMBER = "testNumber";
23      final static String TEST_FILENAME = "testFilename";
24      final static int TEST_INDEX = 5;
25
26      ArrayList<Entry> expected;
27
28      @BeforeEach
29      public void setUp(){
30          mf = mock(ModuleF.class);
31          mg = mock(ModuleG.class);
32
33          md = new ModuleD(mf, mg);
34
35          expected = new ArrayList<>() {{
36              for (int i = 0; i < 10; i += 1)
37                  add(new Entry(TEST_NAME + i, TEST_NUMBER + i));
38          }};
39      }
40
41      @AfterEach
42      public void after(TestInfo testInfo){
43          if(testInfo.getTags().contains("SkipAfter")) {
44              return;
45          }
46          verify(mf, times(1)).displayData(any());
47          verify(mg, times(1)).updateData(anyString(), any());
48      }
49
50      @Test
51      public void insertDataTest(){
52          ArrayList<Entry> ret=
            ↪  md.insertData((ArrayList<Entry>)expected.clone(),
            ↪  TEST_NAME, TEST_NUMBER, TEST_FILENAME);
53
54          expected.add(new Entry(TEST_NAME, TEST_NUMBER));
55
56          TestUtil.compareArrayOfEntries(expected, ret);
57      }
58
59      @Test
60      public void updateDataTest(){
61          ArrayList<Entry> ret = md.updateData((ArrayList<Entry>)
            ↪  expected.clone(), TEST_INDEX, TEST_NAME, TEST_NUMBER,
            ↪  TEST_FILENAME);
62
```

```
63          expected.set(TEST_INDEX, new Entry(TEST_NAME,
            ↪  TEST_NUMBER));
64
65          TestUtil.compareArrayOfEntries(expected, ret);
66      }
67
68      @Test
69      public void deleteDataTest(){
70          ArrayList<Entry> ret = md.deleteData((ArrayList<Entry>)
            ↪  expected.clone(), TEST_INDEX, TEST_FILENAME);
71
72          expected.remove(TEST_INDEX);
73
74          TestUtil.compareArrayOfEntries(expected, ret);
75      }
76
77      @Tag("SkipAfter")
78      @Test
79      public void setFTest(){
80          ModuleF newF = mock(ModuleF.class);
81          md.setF(newF);
82      }
83
84      @Tag("SkipAfter")
85      @Test
86      public void setGTest(){
87          ModuleG newG = mock(ModuleG.class);
88          md.setG(newG);
89      }
90
91  }
```

A.5 Module E

```
1   package bigbang;
2   import static org.junit.jupiter.api.Assertions.*;
3
4   import modules.ModuleE;
5   import org.junit.jupiter.api.Test;
6
7   public class TestE {
8
9       @Test
10      public void testE(){
11          assertThrows(ModuleE.DataBaseExitException.class , ()->
            ↪  new ModuleE().exitProgram());
```

```
    }

}
```

A.6 Module F

```
package bigbang;

import data.Entry;
import modules.ModuleF;
import org.junit.jupiter.api.Test;
import static org.junit.jupiter.api.Assertions.*;

import java.io.ByteArrayOutputStream;
import java.io.PrintStream;
import java.util.ArrayList;

public class TestF {


    @Test
    public void testModuleF(){
        ByteArrayOutputStream stdout = new
        ↪  ByteArrayOutputStream();

        ModuleF mf = new ModuleF();
        mf.setOutputStream(new PrintStream(stdout));

        ArrayList<Entry> entries = new ArrayList<>();
        entries.add(new Entry("name1", "number1"));
        entries.add(new Entry("name2", "number2"));
        entries.add(new Entry("name3", "number3"));
        entries.add(new Entry("name4", "number4"));
        entries.add(new Entry("name5", "number5"));

        mf.displayData(entries);

        assertEquals("""
Current Data:
1 name1, number1
2 name2, number2
3 name3, number3
4 name4, number4
5 name5, number5
""", stdout.toString());
    }
```

```
}
```

A.7 Module G

```
package bigbang;

import data.Entry;
import modules.ModuleG;
import org.junit.jupiter.api.*;
import static org.junit.jupiter.api.Assertions.*;

import java.io.ByteArrayOutputStream;
import java.io.File;
import java.io.IOException;
import java.io.PrintStream;
import java.nio.file.Files;
import java.nio.file.Paths;
import java.util.ArrayList;

public class TestG {

    static String FILENAME = "GTEST_FILE";
    static File f;
    static ModuleG mg;

    @BeforeEach
    public void createFile(){
        f = new File(FILENAME);
        mg = new ModuleG();
    }

    @AfterEach
    public void deleteFile(){
        f.delete();
    }

    @Test
    public void testModuleG() throws IOException {

        ArrayList<Entry> entries = new ArrayList<>();
        entries.add(new Entry("name1", "number1"));
        entries.add(new Entry("name2", "number2"));
        entries.add(new Entry("name3", "number3"));
        entries.add(new Entry("name4", "number4"));
        entries.add(new Entry("name5", "number5"));

```

```
43          mg.updateData(FILENAME, entries);
44
45          // todo test output
46          assertEquals("""
47  name1,number1
48  name2,number2
49  name3,number3
50  name4,number4
51  name5,number5
52  """, Files.readString(Paths.get(FILENAME)));
53      }
54
55      @Test
56      public void testModuleGFail() {
57          ByteArrayOutputStream stdout= new ByteArrayOutputStream();
58          System.setOut(new PrintStream(stdout));
59          mg.updateData("", new ArrayList<Entry>());
60
61          assertEquals("Error updating DB File.\n", stdout.toString());
62      }
63  }
```

A.8 Test Everything

```
1   package bigbang;
2
3   import modules.*;
4   import org.junit.jupiter.api.AfterEach;
5   import org.junit.jupiter.api.BeforeEach;
6   import org.junit.jupiter.api.Test;
7   import org.mockito.Mockito;
8
9   import java.io.ByteArrayOutputStream;
10  import java.io.File;
11  import java.io.IOException;
12  import java.io.PrintStream;
13  import java.nio.file.Files;
14  import java.nio.file.Paths;
15
16  import static org.junit.jupiter.api.Assertions.assertEquals;
17  import static org.junit.jupiter.api.Assertions.assertThrows;
18  import static org.mockito.ArgumentMatchers.*;
19  import static org.mockito.Mockito.*;
20
21
22  public class Test_Everything {
```

```
23
24      ModuleA ma;
25      ModuleB mb;
26      ModuleC mc;
27      ModuleD md;
28      ModuleE me;
29      ModuleF mf;
30      ModuleG mg;
31      final static String TEST_FILENAME = "testFileName";
32      final static String NONEXISTENT_FILE = "nonExistentFile";
33
34      File f;
35
36      ByteArrayOutputStream stdout;
37
38      @BeforeEach
39      public void setUp() throws IOException {
40          me = Mockito.spy(new ModuleE());
41          mf = Mockito.spy(new ModuleF());
42          mg = Mockito.spy(new ModuleG());
43
44          mb = Mockito.spy(new ModuleB(mf));
45          mc = Mockito.spy(new ModuleC(mf));
46          md = Mockito.spy(new ModuleD(mf, mg));
47
48          ma = new ModuleA(mb, mc, md, me);
49
50          newStdout();
51
52          f = new File(TEST_FILENAME);
53          f.createNewFile();
54      }
55
56      @AfterEach
57      public void deleteFile() throws IOException {
58
            ↪  System.out.println(Files.readString(Paths.get(TEST_FILENAME)));
59          f.delete();
60      }
61
62      public void newStdout(){
63          stdout = new ByteArrayOutputStream();
64          ma.setOutputStream(new PrintStream(stdout));
65      }
66
67      @Test
```

```
68      public void testHelp() throws ModuleE.DataBaseExitException {
69          ma.run(new String[]{"help"});
70
71          final String help = "Available Commands: \n" +
72                  "load <filepath>\n" +
73                  "add <name> <number>\n" +
74                  "update <index> <name> <number>\n" +
75                  "delete <index>\n" +
76                  "sort\n" +
77                  "exit";
78
79          assertEquals(help + "\n", stdout.toString());
80
81      }
82
83      public void load() throws ModuleE.DataBaseExitException {
84  //          Mockito.when(md.insertData(any(), anyString(),
    ↪  anyString(), anyString())).thenReturn(new
    ↪  ArrayList<Entry>());
85          ma.run(new String[]{"load", TEST_FILENAME});
86      }
87
88      @Test
89      public void testLoad() throws ModuleE.DataBaseExitException {
90          load();
91          verify(mb, times(1)).loadFile(anyString());
92      }
93
94      @Test
95      public void testLoadNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
96          ma.run(new String[]{"load"});
97          assertEquals("Malformed command!\n", stdout.toString());
98          verify(mb, never()).loadFile(anyString());
99      }
100
101     @Test
102     public void testLoadBReturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
103 //
    ↪  Mockito.when(mb.loadFile(anyString())).thenReturn(null);
104         ma.run(new String[]{"load", NONEXISTENT_FILE});
105         verify(mb, times(1)).loadFile(anyString());
106     }
107
108     @Test
```

```
109     public void testAddNoData() throws
        ↪  ModuleE.DataBaseExitException {
110         ma.run(new String[]{"add", "name", "number"});
111         assertEquals("No file loaded!\n", stdout.toString());
112         verify(md, never()).insertData(any(), anyString(),
            ↪  anyString(), anyString());
113     }
114
115     @Test
116     public void testAdd() throws ModuleE.DataBaseExitException,
        ↪  IOException {
117 //        Mockito.when(md.insertData(any(), anyString(),
    ↪  anyString(), anyString())).thenReturn(new
    ↪  ArrayList<Entry>());
118         ma.run(new String[]{"load", TEST_FILENAME});
119         ma.run(new String[]{"add", "name", "number"});
120         verify(md, times(1)).insertData(any(), anyString(),
            ↪  anyString(), anyString());
121
122         assertEquals("name,number\n",
            ↪  Files.readString(Paths.get(TEST_FILENAME)));
123     }
124
125     @Test
126     public void testAddDreturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
127
128         // through static analysis, we can see that d.insertdata
            ↪  will never return null in practice
129
130 //        Mockito.when(md.insertData(any(), anyString(),
    ↪  anyString(), anyString())).thenReturn(null);
131 //        ma.run(new String[]{"load", NONEXISTENT_FILE});
132 //        ma.run(new String[]{"add", "name", "number"});
133 //        verify(md, times(1)).insertData(any(), anyString(),
    ↪  anyString(), anyString());
134     }
135
136     @Test
137     public void testAddNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
138         ma.run(new String[]{"load", TEST_FILENAME});
139         ma.run(new String[]{"add"});
140         assertEquals("Malformed command!\n", stdout.toString());
141         verify(md, never()).insertData(any(), anyString(),
            ↪  anyString(), anyString());
```

```
142     }
143
144     @Test
145     public void testSort() throws ModuleE.DataBaseExitException,
        ↪ IOException {
146         ma.run(new String[]{"load", TEST_FILENAME});
147         ma.run(new String[]{"add", "ddd", "aaa"});
148         ma.run(new String[]{"add", "bbb", "bbb"});
149         ma.run(new String[]{"add", "ccc", "ccc"});
150         ma.run(new String[]{"add", "aaa", "aaa"});
151         ma.run(new String[]{"add", "ccc", "aaa"});
152         ma.run(new String[]{"add", "bbb", "aaa"});
153
154
155         ma.run(new String[]{"sort"});
156         verify(mc, times(1)).sortData(any());
157
158         assertEquals("""
159 aaa,aaa
160 bbb,aaa
161 bbb,bbb
162 ccc,aaa,
163 ccc,ccc
164 ddd,aaa""", Files.readString(Paths.get(TEST_FILENAME)));
165     }
166
167     @Test
168     public void testSortNoData() throws
        ↪ ModuleE.DataBaseExitException {
169         ma.run(new String[]{"sort"});
170         assertEquals("No file loaded!\n", stdout.toString());
171         verify(mc, never()).sortData(any());
172     }
173
174     @Test
175     public void testSortCReturnsNull() throws
        ↪ ModuleE.DataBaseExitException {
176         // in practice, moduleC never returns null
177         // it can throw a NullPointerException if the input data
            ↪  is null
178         // but the program does a null check on line 56 in module
            ↪  A
179         // so it will never return null
180
181 //        Mockito.when(mc.sortData(any())).thenReturn(null);
182 //        ma.run(new String[]{"load", TEST_FILENAME});
```

```
183 //         ma.run(new String[]{"sort"});
184 //         verify(mc, times(1)).sortData(any());
185     }
186
187     @Test
188     public void testUpdate() throws
        ↪  ModuleE.DataBaseExitException, IOException {
189         ma.run(new String[]{"load", TEST_FILENAME});
190         ma.run(new String[]{"add", "aaa", "aaa"});
191         ma.run(new String[]{"add", "bbb", "aaa"});
192         ma.run(new String[]{"add", "bbb", "bbb"});
193         ma.run(new String[]{"add", "ccc", "aaa"});
194         ma.run(new String[]{"add", "ccc", "ccc"});
195         ma.run(new String[]{"add", "ddd", "aaa"});
196
197         ma.run(new String[]{"update", "5", "new", "data"});
198
199         verify(md, times(1)).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
200
201         assertEquals("""
202 aaa,aaa
203 bbb,aaa
204 bbb,bbb
205 ccc,aaa
206 new,data
207 ddd,aaa
208 """, Files.readString(Paths.get(TEST_FILENAME)));
209
210         // huh this seems to pass
211         // talk about in the report how on line 138 they do
            ↪  index-2
212         // and how the error cancels out that way to be correct
            ↪  in the end
213     }
214
215     @Test
216     public void testUpdateInvalidArguments() throws
        ↪  ModuleE.DataBaseExitException {
217         ma.run(new String[]{"load", TEST_FILENAME});
218         ma.run(new String[]{"update", "arg1", "arg2", "arg3"});
219         verify(md, never()).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
220     }
221
222
```

```
223     @Test
224     public void testUpdateNoData() throws
        ↪  ModuleE.DataBaseExitException {
225         ma.run(new String[]{"update", "1", "2", "3"});
226         assertEquals("No file loaded!\n", stdout.toString());
227         verify(md, never()).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
228     }
229
230     @Test
231     public void testUpdateCReturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
232
233 //        in practice, we see using static analysis that moduleC
    ↪  can never return null
234
235 //        Mockito.when(md.updateData(any(), anyInt(),
    ↪  anyString(), anyString(), anyString())).thenReturn(null);
236 //        ma.run(new String[]{"load", NONEXISTENT_FILE});
237 //        ma.run(new String[]{"update", "1", "2", "3"});
238 //        verify(md, times(1)).updateData(any(), anyInt(),
    ↪  anyString(), anyString(), anyString());
239     }
240
241     @Test
242     public void testUpdateNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
243         ma.run(new String[]{"load", TEST_FILENAME});
244         ma.run(new String[]{"update"});
245         assertEquals("Malformed command!\n", stdout.toString());
246         verify(md, never()).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
247     }
248
249     @Test
250     public void testDelete() throws
        ↪  ModuleE.DataBaseExitException, IOException {
251         ma.run(new String[]{"load", TEST_FILENAME});
252         ma.run(new String[]{"add", "aaa", "aaa"});
253         ma.run(new String[]{"add", "bbb", "aaa"});
254         ma.run(new String[]{"add", "bbb", "bbb"});
255         ma.run(new String[]{"add", "ccc", "aaa"});
256         ma.run(new String[]{"add", "ccc", "ccc"});
257         ma.run(new String[]{"add", "ddd", "aaa"});
258
259         ma.run(new String[]{"delete", "5"});
```

```
260             verify(md, times(1)).deleteData(any(), anyInt(),
                ↪  anyString());
261
262             assertEquals("""
263     aaa,aaa
264     bbb,aaa
265     bbb,bbb
266     ccc,aaa
267     ddd,aaa
268     """, Files.readString(Paths.get(TEST_FILENAME)));
269         }
270
271         @Test
272         public void testDeleteInvalidArguments() throws
                ↪  ModuleE.DataBaseExitException {
273             ma.run(new String[]{"load", TEST_FILENAME});
274             ma.run(new String[]{"delete", "arg1"});
275             verify(md, never()).deleteData(any(), anyInt(),
                ↪  anyString());
276         }
277
278         @Test
279         public void testDeleteNoData() throws
                ↪  ModuleE.DataBaseExitException {
280             ma.run(new String[]{"delete"});
281             assertEquals("No file loaded!\n", stdout.toString());
282             verify(md, never()).deleteData(any(), anyInt(),
                ↪  anyString());
283         }
284
285         @Test
286         public void testDeleteDReturnsNull() throws
                ↪  ModuleE.DataBaseExitException {
287
288             // using static analysis, we see that in practice,
                ↪  deleteData will never return null
289     //          Mockito.when(md.deleteData(any(), anyInt(),
        ↪  anyString())).thenReturn(null);
290     //          ma.run(new String[]{"load", NONEXISTENT_FILE});
291     //          ma.run(new String[]{"delete", "1"});
292     //          verify(md, times(1)).deleteData(any(), anyInt(),
        ↪  anyString());
293         }
294
295         @Test
```

```
296     public void testDeleteNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
297         ma.run(new String[]{"load", TEST_FILENAME});
298         ma.run(new String[]{"delete"});
299         assertEquals("Malformed command!\n", stdout.toString());
300         verify(md, never()).deleteData(any(), anyInt(),
            ↪  anyString());
301     }
302
303     @Test
304     public void testExit() throws ModuleE.DataBaseExitException {
305 //
    ↪  Mockito.doThrow(ModuleE.DataBaseExitException.class).when(me).exitProgram();
306         assertThrows(ModuleE.DataBaseExitException.class, ()
            ↪  ->ma.run(new String[]{"exit"}));
307         // line 147 does not get covered, because the program
            ↪  exits
308     }
309 }
```

B Bottom Up Testing Strategy

B.1 Test F

```
1  package bottumUp;
2
3  import data.Entry;
4  import modules.ModuleF;
5  import org.junit.jupiter.api.Test;
6
7  import java.io.ByteArrayOutputStream;
8  import java.io.PrintStream;
9  import java.util.ArrayList;
10
11 import static org.junit.jupiter.api.Assertions.assertEquals;
12
13 public class Test00_F {
14
15
16     @Test
17     public void testModuleF(){
18         ByteArrayOutputStream stdout = new
           ↪  ByteArrayOutputStream();
19
20         ModuleF mf = new ModuleF();
```

```
        mf.setOutputStream(new PrintStream(stdout));

        ArrayList<Entry> entries = new ArrayList<>();
        entries.add(new Entry("name1", "number1"));
        entries.add(new Entry("name2", "number2"));
        entries.add(new Entry("name3", "number3"));
        entries.add(new Entry("name4", "number4"));
        entries.add(new Entry("name5", "number5"));

        mf.displayData(entries);

        assertEquals("""
Current Data:
1 name1, number1
2 name2, number2
3 name3, number3
4 name4, number4
5 name5, number5
""", stdout.toString());
    }
}
```

B.2 Test G

```
package bottumUp;

import data.Entry;
import modules.ModuleG;
import org.junit.jupiter.api.AfterEach;
import org.junit.jupiter.api.BeforeEach;
import org.junit.jupiter.api.Test;

import java.io.ByteArrayOutputStream;
import java.io.File;
import java.io.IOException;
import java.io.PrintStream;
import java.nio.file.Files;
import java.nio.file.Paths;
import java.util.ArrayList;

import static org.junit.jupiter.api.Assertions.assertEquals;

public class Test01_G {

    static String FILENAME = "GTEST_FILE";
    static File f;
```

```
23      static ModuleG mg;
24
25      @BeforeEach
26      public void createFile(){
27          f = new File(FILENAME);
28          mg = new ModuleG();
29      }
30
31      @AfterEach
32      public void deleteFile(){
33          f.delete();
34      }
35
36      @Test
37      public void testModuleG() throws IOException {
38
39          ArrayList<Entry> entries = new ArrayList<>();
40          entries.add(new Entry("name1", "number1"));
41          entries.add(new Entry("name2", "number2"));
42          entries.add(new Entry("name3", "number3"));
43          entries.add(new Entry("name4", "number4"));
44          entries.add(new Entry("name5", "number5"));
45
46          mg.updateData(FILENAME, entries);
47
48          // todo test output
49          assertEquals("""
50  name1,number1
51  name2,number2
52  name3,number3
53  name4,number4
54  name5,number5
55  """, Files.readString(Paths.get(FILENAME)));
56      }
57
58      @Test
59      public void testModuleGFail() {
60          ByteArrayOutputStream stdout= new
            ↪  ByteArrayOutputStream();
61          System.setOut(new PrintStream(stdout));
62          mg.updateData("", new ArrayList<Entry>());
63
64          assertEquals("Error updating DB File.\n",
            ↪  stdout.toString());
65      }
66  }
```

B.3 Test BF

```java
package bottumUp;

import TestUtil.TestUtil;
import modules.ModuleB;
import modules.ModuleF;
import org.junit.jupiter.api.AfterEach;
import org.junit.jupiter.api.BeforeEach;
import org.junit.jupiter.api.Test;

import java.io.File;
import java.io.IOException;
import java.nio.file.Files;
import data.Entry;
import java.nio.file.Paths;
import java.util.ArrayList;

import static org.mockito.Mockito.mock;

// IO Exception catching is not tested
// Explain in the report that it's just calling a library function
// Also, the scenario was never encountered e.g. reading /etc/shadow

public class Test02_BF {

    ModuleB mb;
    ModuleF mf;
    final static String TEST_FILENAME = "BFTEST_FILE";
    static File f;

    @BeforeEach
    public void setUp() throws IOException {
        mf = new ModuleF();
        mb = new ModuleB(mf);

        f = new File(TEST_FILENAME);
        f.createNewFile();
        Files.writeString(Paths.get(TEST_FILENAME), """
This
is,some
test
data""");
    }
```

```
43
44      @AfterEach
45      public void tearDown(){
46          f.delete();
47      }
48
49      @Test
50      public void loadFileTestValidFile() {
51          ArrayList<Entry> ret =  mb.loadFile(TEST_FILENAME);
52
53          ArrayList<Entry> expected = new ArrayList<>() {{
54              add(new Entry("is", "some"));
55          }};
56
57          TestUtil.compareArrayOfEntries(expected, ret);
58      }
59
60      @Test
61      public void loadFileTestInValidFile()  {
62          mb.loadFile("/");
63      }
64
65      @Test
66      public void loadFileTestFileNotFound(){
67          mb.loadFile("");
68      }
69
70      @Test
71      public void setFTest(){
72          ModuleF newF = new ModuleF();
73          mb.setF(newF);
74      }
75  }
```

B.4 Test CF

```
1   package bottumUp;
2
3   import TestUtil.TestUtil;
4   import data.Entry;
5   import modules.ModuleC;
6   import modules.ModuleF;
7   import org.junit.jupiter.api.BeforeEach;
8   import org.junit.jupiter.api.Test;
9
10  import java.util.ArrayList;
```

```
11
12  public class Test03_CF {
13
14      ModuleF mf;
15      ModuleC mc;
16
17      @BeforeEach
18      public void setUp(){
19          mf = new ModuleF();
20          mc = new ModuleC(mf);
21      }
22
23      @Test
24      public void sortDataTest(){
25
26          final String TEST_NAME = "testName";
27          final String TEST_NUMBER = "testNumber";
28
29          ArrayList<Entry> unsorted = new ArrayList<>() {{
30              add(new Entry("ddd", "aaa"));
31              add(new Entry("bbb", "bbb"));
32              add(new Entry("ccc", "ccc"));
33              add(new Entry("aaa", "aaa"));
34              add(new Entry("ccc", "aaa"));
35              add(new Entry("bbb", "aaa"));
36          }};
37
38          ArrayList<Entry> sorted = new ArrayList<>() {{
39              add(new Entry("aaa", "aaa"));
40              add(new Entry("bbb", "aaa"));
41              add(new Entry("bbb", "bbb"));
42              add(new Entry("ccc", "aaa"));
43              add(new Entry("ccc", "ccc"));
44              add(new Entry("ddd", "aaa"));
45          }};
46          ArrayList<Entry> ret = mc.sortData(unsorted);
47
48          TestUtil.compareArrayOfEntries(sorted, ret);
49      }
50
51      @Test
52      public void setFTest(){
53          ModuleF newF = new ModuleF();
54          mc.setF(newF);
55      }
56
```

```
57      // to cover line 28 in ModuleC
58      @Test
59      public void sortFourElementsTest(){
60          ArrayList<Entry> unsorted = new ArrayList<>() {{
61              add(new Entry("ccc", "ccc"));
62              add(new Entry("aaa", "aaa"));
63              add(new Entry("bbb", "ddd"));
64              add(new Entry("bbb", "aaa"));
65          }};
66
67          ArrayList<Entry> sorted = new ArrayList<>() {{
68              add(new Entry("aaa", "aaa"));
69              add(new Entry("bbb", "aaa"));
70              add(new Entry("bbb", "ddd"));
71              add(new Entry("ccc", "ccc"));
72          }};
73
74          ArrayList<Entry> ret = mc.sortData(unsorted);
75
76          TestUtil.compareArrayOfEntries(sorted, ret);
77      }
78
79  }
```

B.5 Test DFG

```
1   package bottumUp;
2
3   import TestUtil.TestUtil;
4   import data.Entry;
5   import modules.ModuleD;
6   import modules.ModuleF;
7   import modules.ModuleG;
8   import org.junit.jupiter.api.*;
9
10  import java.util.ArrayList;
11
12  import static org.mockito.Mockito.*;
13
14
15  public class Test04_DFG {
16
17      ModuleF mf;
18      ModuleG mg;
19      ModuleD md;
20
```

```
21      final static String TEST_NAME = "testName";
22      final static String TEST_NUMBER = "testNumber";
23      final static String TEST_FILENAME = "testFilename";
24      final static int TEST_INDEX = 5;
25
26      ArrayList<Entry> expected;
27
28      @BeforeEach
29      public void setUp(){
30          mf = spy(new ModuleF());
31          mg = spy(new ModuleG());
32
33          md = new ModuleD(mf, mg);
34
35          expected = new ArrayList<>() {{
36              for (int i = 0; i < 10; i += 1)
37                  add(new Entry(TEST_NAME + i, TEST_NUMBER + i));
38          }};
39      }
40
41      @AfterEach
42      public void after(TestInfo testInfo){
43          if(testInfo.getTags().contains("SkipAfter")) {
44              return;
45          }
46          verify(mf, times(1)).displayData(any());
47          verify(mg, times(1)).updateData(anyString(), any());
48      }
49
50      @Test
51      public void insertDataTest(){
52          ArrayList<Entry> ret=
            ↪  md.insertData((ArrayList<Entry>)expected.clone(),
            ↪  TEST_NAME, TEST_NUMBER, TEST_FILENAME);
53
54          expected.add(new Entry(TEST_NAME, TEST_NUMBER));
55
56          TestUtil.compareArrayOfEntries(expected, ret);
57      }
58
59      @Test
60      public void updateDataTest(){
61          ArrayList<Entry> ret = md.updateData((ArrayList<Entry>)
            ↪  expected.clone(), TEST_INDEX, TEST_NAME, TEST_NUMBER,
            ↪  TEST_FILENAME);
62
```

```
63          expected.set(TEST_INDEX, new Entry(TEST_NAME,
            ↪  TEST_NUMBER));
64
65          TestUtil.compareArrayOfEntries(expected, ret);
66      }
67
68      @Test
69      public void deleteDataTest(){
70          ArrayList<Entry> ret = md.deleteData((ArrayList<Entry>)
            ↪  expected.clone(), TEST_INDEX, TEST_FILENAME);
71
72          expected.remove(TEST_INDEX);
73
74          TestUtil.compareArrayOfEntries(expected, ret);
75      }
76
77      @Tag("SkipAfter")
78      @Test
79      public void setFTest(){
80          ModuleF newF = new ModuleF();
81          md.setF(newF);
82      }
83
84      @Tag("SkipAfter")
85      @Test
86      public void setGTest(){
87          ModuleG newG = new ModuleG();
88          md.setG(newG);
89      }
90
91  }
```

B.6 Test E

```
1   package bottumUp;
2
3   import modules.ModuleE;
4   import org.junit.jupiter.api.Test;
5
6   import static org.junit.jupiter.api.Assertions.assertThrows;
7
8   public class Test05_E {
9
10      @Test
11      public void testE(){
```

```
12          assertThrows(ModuleE.DataBaseExitException.class , ()->
            ↪  new ModuleE().exitProgram());
13      }
14
15  }
```

B.7 Test Everything

```
1   package bottumUp;
2
3   import modules.*;
4   import org.junit.jupiter.api.AfterEach;
5   import org.junit.jupiter.api.BeforeEach;
6   import org.junit.jupiter.api.Test;
7   import org.mockito.Mockito;
8
9   import java.io.ByteArrayOutputStream;
10  import java.io.File;
11  import java.io.IOException;
12  import java.io.PrintStream;
13  import java.nio.file.Files;
14  import java.nio.file.Paths;
15
16  import static org.junit.jupiter.api.Assertions.assertEquals;
17  import static org.junit.jupiter.api.Assertions.assertThrows;
18  import static org.mockito.ArgumentMatchers.*;
19  import static org.mockito.Mockito.*;
20
21
22  public class Test06_Everything {
23
24      ModuleA ma;
25      ModuleB mb;
26      ModuleC mc;
27      ModuleD md;
28      ModuleE me;
29      ModuleF mf;
30      ModuleG mg;
31      final static String TEST_FILENAME = "testFileName";
32      final static String NONEXISTENT_FILE = "nonExistentFile";
33
34      File f;
35
36      ByteArrayOutputStream stdout;
37
38      @BeforeEach
```

```
39      public void setUp() throws IOException {
40          me = Mockito.spy(new ModuleE());
41          mf = Mockito.spy(new ModuleF());
42          mg = Mockito.spy(new ModuleG());
43
44          mb = Mockito.spy(new ModuleB(mf));
45          mc = Mockito.spy(new ModuleC(mf));
46          md = Mockito.spy(new ModuleD(mf, mg));
47
48          ma = new ModuleA(mb, mc, md, me);
49
50          newStdout();
51
52          f = new File(TEST_FILENAME);
53          f.createNewFile();
54      }
55
56      @AfterEach
57      public void deleteFile() throws IOException {
58
            ↪  System.out.println(Files.readString(Paths.get(TEST_FILENAME)));
59          f.delete();
60      }
61
62      public void newStdout(){
63          stdout = new ByteArrayOutputStream();
64          ma.setOutputStream(new PrintStream(stdout));
65      }
66
67      @Test
68      public void testHelp() throws ModuleE.DataBaseExitException {
69          ma.run(new String[]{"help"});
70
71          final String help = "Available Commands: \n" +
72                  "load <filepath>\n" +
73                  "add <name> <number>\n" +
74                  "update <index> <name> <number>\n" +
75                  "delete <index>\n" +
76                  "sort\n" +
77                  "exit";
78
79          assertEquals(help + "\n", stdout.toString());
80
81      }
82
83      public void load() throws ModuleE.DataBaseExitException {
```

```
84  //        Mockito.when(md.insertData(any(), anyString(),
    ↪  anyString(), anyString())).thenReturn(new
    ↪  ArrayList<Entry>());
85          ma.run(new String[]{"load", TEST_FILENAME});
86      }
87
88      @Test
89      public void testLoad() throws ModuleE.DataBaseExitException {
90          load();
91          verify(mb, times(1)).loadFile(anyString());
92      }
93
94      @Test
95      public void testLoadNoArgument() throws
        ↪  ModuleE.DataBaseExitException {
96          ma.run(new String[]{"load"});
97          assertEquals("Malformed command!\n", stdout.toString());
98          verify(mb, never()).loadFile(anyString());
99      }
100
101     @Test
102     public void testLoadBReturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
103 //
    ↪  Mockito.when(mb.loadFile(anyString())).thenReturn(null);
104         ma.run(new String[]{"load", NONEXISTENT_FILE});
105         verify(mb, times(1)).loadFile(anyString());
106     }
107
108     @Test
109     public void testAddNoData() throws
        ↪  ModuleE.DataBaseExitException {
110         ma.run(new String[]{"add", "name", "number"});
111         assertEquals("No file loaded!\n", stdout.toString());
112         verify(md, never()).insertData(any(), anyString(),
            ↪  anyString(), anyString());
113     }
114
115     @Test
116     public void testAdd() throws ModuleE.DataBaseExitException,
        ↪  IOException {
117 //        Mockito.when(md.insertData(any(), anyString(),
    ↪  anyString(), anyString())).thenReturn(new
    ↪  ArrayList<Entry>());
118         ma.run(new String[]{"load", TEST_FILENAME});
119         ma.run(new String[]{"add", "name", "number"});
```

```
120             verify(md, times(1)).insertData(any(), anyString(),
                ↪  anyString(), anyString());
121
122             assertEquals("name,number\n",
                ↪  Files.readString(Paths.get(TEST_FILENAME)));
123         }
124
125         @Test
126         public void testAddDreturnsNull() throws
            ↪  ModuleE.DataBaseExitException {
127
128             // through static analysis, we can see that d.insertdata
                ↪  will never return null in practice
129
130 //          Mockito.when(md.insertData(any(), anyString(),
    ↪  anyString(), anyString())).thenReturn(null);
131 //          ma.run(new String[]{"load", NONEXISTENT_FILE});
132 //          ma.run(new String[]{"add", "name", "number"});
133 //          verify(md, times(1)).insertData(any(), anyString(),
    ↪  anyString(), anyString());
134         }
135
136         @Test
137         public void testAddNoArgument() throws
            ↪  ModuleE.DataBaseExitException {
138             ma.run(new String[]{"load", TEST_FILENAME});
139             ma.run(new String[]{"add"});
140             assertEquals("Malformed command!\n", stdout.toString());
141             verify(md, never()).insertData(any(), anyString(),
                ↪  anyString(), anyString());
142         }
143
144         @Test
145         public void testSort() throws ModuleE.DataBaseExitException,
            ↪  IOException {
146             ma.run(new String[]{"load", TEST_FILENAME});
147             ma.run(new String[]{"add", "ddd", "aaa"});
148             ma.run(new String[]{"add", "bbb", "bbb"});
149             ma.run(new String[]{"add", "ccc", "ccc"});
150             ma.run(new String[]{"add", "aaa", "aaa"});
151             ma.run(new String[]{"add", "ccc", "aaa"});
152             ma.run(new String[]{"add", "bbb", "aaa"});
153
154
155             ma.run(new String[]{"sort"});
156             verify(mc, times(1)).sortData(any());
```

```
157
158             assertEquals("""
159     aaa,aaa
160     bbb,aaa
161     bbb,bbb
162     ccc,aaa,
163     ccc,ccc
164     ddd,aaa""", Files.readString(Paths.get(TEST_FILENAME)));
165         }
166
167         @Test
168         public void testSortNoData() throws
            ↪ ModuleE.DataBaseExitException {
169             ma.run(new String[]{"sort"});
170             assertEquals("No file loaded!\n", stdout.toString());
171             verify(mc, never()).sortData(any());
172         }
173
174         @Test
175         public void testSortCReturnsNull() throws
            ↪ ModuleE.DataBaseExitException {
176             // in practice, moduleC never returns null
177             // it can throw a NullPointerException if the input data
                ↪  is null
178             // but the program does a null check on line 56 in module
                ↪  A
179             // so it will never return null
180
181     //        Mockito.when(mc.sortData(any())).thenReturn(null);
182     //        ma.run(new String[]{"load", TEST_FILENAME});
183     //        ma.run(new String[]{"sort"});
184     //        verify(mc, times(1)).sortData(any());
185         }
186
187         @Test
188         public void testUpdate() throws
            ↪ ModuleE.DataBaseExitException, IOException {
189             ma.run(new String[]{"load", TEST_FILENAME});
190             ma.run(new String[]{"add", "aaa", "aaa"});
191             ma.run(new String[]{"add", "bbb", "aaa"});
192             ma.run(new String[]{"add", "bbb", "bbb"});
193             ma.run(new String[]{"add", "ccc", "aaa"});
194             ma.run(new String[]{"add", "ccc", "ccc"});
195             ma.run(new String[]{"add", "ddd", "aaa"});
196
197             ma.run(new String[]{"update", "5", "new", "data"});
```

```
198
199         verify(md, times(1)).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
200
201         assertEquals("""
202 aaa,aaa
203 bbb,aaa
204 bbb,bbb
205 ccc,aaa
206 new,data
207 ddd,aaa
208 """, Files.readString(Paths.get(TEST_FILENAME)));
209
210         // huh this seems to pass
211         // talk about in the report how on line 138 they do
            ↪  index-2
212         // and how the error cancels out that way to be correct
            ↪  in the end
213     }
214
215     @Test
216     public void testUpdateInvalidArguments() throws
        ↪  ModuleE.DataBaseExitException {
217         ma.run(new String[]{"load", TEST_FILENAME});
218         ma.run(new String[]{"update", "arg1", "arg2", "arg3"});
219         verify(md, never()).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
220     }
221
222
223     @Test
224     public void testUpdateNoData() throws
        ↪  ModuleE.DataBaseExitException {
225         ma.run(new String[]{"update", "1", "2", "3"});
226         assertEquals("No file loaded!\n", stdout.toString());
227         verify(md, never()).updateData(any(), anyInt(),
            ↪  anyString(), anyString(), anyString());
228     }
229
230     @Test
231     public void testUpdateCReturnsNull() throws
        ↪  ModuleE.DataBaseExitException {
232
233 //        in practce, we see using static analysis that moduleC
    ↪  can never return null
234
```

```
235 //        Mockito.when(md.updateData(any(), anyInt(),
    ↪ anyString(), anyString(), anyString())).thenReturn(null);
236 //        ma.run(new String[]{"load", NONEXISTENT_FILE});
237 //        ma.run(new String[]{"update", "1", "2", "3"});
238 //        verify(md, times(1)).updateData(any(), anyInt(),
    ↪ anyString(), anyString(), anyString());
239     }
240
241     @Test
242     public void testUpdateNoArgument() throws
        ↪ ModuleE.DataBaseExitException {
243         ma.run(new String[]{"load", TEST_FILENAME});
244         ma.run(new String[]{"update"});
245         assertEquals("Malformed command!\n", stdout.toString());
246         verify(md, never()).updateData(any(), anyInt(),
            ↪ anyString(), anyString(), anyString());
247     }
248
249     @Test
250     public void testDelete() throws
        ↪ ModuleE.DataBaseExitException, IOException {
251         ma.run(new String[]{"load", TEST_FILENAME});
252         ma.run(new String[]{"add", "aaa", "aaa"});
253         ma.run(new String[]{"add", "bbb", "aaa"});
254         ma.run(new String[]{"add", "bbb", "bbb"});
255         ma.run(new String[]{"add", "ccc", "aaa"});
256         ma.run(new String[]{"add", "ccc", "ccc"});
257         ma.run(new String[]{"add", "ddd", "aaa"});
258
259         ma.run(new String[]{"delete", "5"});
260         verify(md, times(1)).deleteData(any(), anyInt(),
            ↪ anyString());
261
262         assertEquals("""
263 aaa,aaa
264 bbb,aaa
265 bbb,bbb
266 ccc,aaa
267 ddd,aaa
268 """, Files.readString(Paths.get(TEST_FILENAME)));
269     }
270
271     @Test
272     public void testDeleteInvalidArguments() throws
        ↪ ModuleE.DataBaseExitException {
273         ma.run(new String[]{"load", TEST_FILENAME});
```

```
274             ma.run(new String[]{"delete", "arg1"});
275             verify(md, never()).deleteData(any(), anyInt(),
                ↪  anyString());
276         }
277
278         @Test
279         public void testDeleteNoData() throws
                ↪  ModuleE.DataBaseExitException {
280             ma.run(new String[]{"delete"});
281             assertEquals("No file loaded!\n", stdout.toString());
282             verify(md, never()).deleteData(any(), anyInt(),
                ↪  anyString());
283         }
284
285         @Test
286         public void testDeleteDReturnsNull() throws
                ↪  ModuleE.DataBaseExitException {
287
288             // using static analysis, we see that in practice,
                ↪  deleteData will never return null
289 //          Mockito.when(md.deleteData(any(), anyInt(),
    ↪  anyString())).thenReturn(null);
290 //          ma.run(new String[]{"load", NONEXISTENT_FILE});
291 //          ma.run(new String[]{"delete", "1"});
292 //          verify(md, times(1)).deleteData(any(), anyInt(),
    ↪  anyString());
293         }
294
295         @Test
296         public void testDeleteNoArgument() throws
                ↪  ModuleE.DataBaseExitException {
297             ma.run(new String[]{"load", TEST_FILENAME});
298             ma.run(new String[]{"delete"});
299             assertEquals("Malformed command!\n", stdout.toString());
300             verify(md, never()).deleteData(any(), anyInt(),
                ↪  anyString());
301         }
302
303         @Test
304         public void testExit() throws ModuleE.DataBaseExitException {
305 //
    ↪  Mockito.doThrow(ModuleE.DataBaseExitException.class).when(me).exitProgram();
306             assertThrows(ModuleE.DataBaseExitException.class, ()
                ↪  ->ma.run(new String[]{"exit"}));
307             // line 147 does not get covered, because the program
                ↪  exits
```

```
308             }
309     }
```