

Unit Testing of the OpenMRS Thread-Safe Circular First-In-First- Out (FIFO) Queue

By: Megan Simpson, George Lutas, and Christian
Ellwood

Table of Contents:

I.	Introduction.....	pg. 1
II.	Explanation of the Testing Framework.....	pg. 2
III.	Chapter 1: Building OpenMRS.....	pg. 6
IV.	Chapter 2: Developing the Test Plan.....	pg. 7
V.	Chapter 3: Designing and Building the Framework.....	pg. 10
VI.	Chapter 4: Extending the Framework.....	pg. 13
VII.	Chapter 5: Fault Injection Testing.....	pg. 15
VIII.	Chapter 6: Lessons and Experiences.....	pg. 17
IX.	Evaluation of Performance.....	pg. 20

Introduction:

This report will serve as a comprehensive recounting of the experiences of Team-6 as we developed an automatic testing framework of the Thread-Safe Circular First-In-First-Out (FIFO) Queue of the OpenMRS Open-Source Project. This framework has been developed to work with any system running with a Bash terminal. OpenMRS is a project developed in Java as a Medical Record Keeping Software and as such, we chose to work with this software with respect to the current Coronavirus-19 pandemic sweeping the world as well as the respectable efforts to help developing nations secure medical data of patients suffering from very serious diseases, such as Acquired ImmunoDeficiency Syndrome (AIDS), Tuberculosis, or Human Immunodeficiency Virus (HIV).

The goals of this system were to gain confidence with automatic testing and the Bash scripting language in order to achieve a comprehensive testing system that can be extended to support an indeterminate number of test cases, as long as the supplied test case follows the format that has been established and any necessary test drivers are supplied. However, in doing so, we uncovered a bug in the system that, while not entirely crippling to the system, could potentially cause issues in the operation of OpenMRS. As of the writing this report, we have not reported this bug, nor do we know the potential severity of this vulnerability.

Explanation, Instructions, and Examples of the Testing Framework

This testing framework is written exclusively in Bash, and as such, provided that there is a Bash terminal accessible to the user at time of running this script, the script should run as expected. The first operation that the script begins to do is to retrieve dependencies that the framework needs to operate. As of now, the dependencies that have been noted and are automatically installed at the running of the script is the Java Runtime Environment (JRE) and the Java Development Kit (JDK). The only input required from the user at this time is to provide the username and password to the system to install these dependencies as well as the credentials for an associated GitHub account. Once the system has installed these dependencies, the terminal is cleared, and the testing begins.

After this point, the OpenMRS code base is retrieved from the GitHub repository, pending authentication to a GitHub account, and is placed into the projects directory, where it will stay until the Team-6 repository is deleted. The script then proceeds to look in the testCases directory and counts the number of files in this directory. As it currently stands, the script assumes that any files in the testCases directory is a test case that contains the same information that the test cases currently in the directory contain. The order is irrelevant for correct operation.

The script parses each file for the test case driver, the test case ID, method being tested, any inputs to the method, and expected value from the test case text file and this is printed to the HTML file that contains the output for each test case. The file being tested is copied into the testCasesExecutables directory and compiled with the test driver that was parsed from the test case file. In order to ensure that all of the pertinent .class files are in the correct locations; the file being tested is compiled with both the -cp and -d flag with both options pointing to the current directory. The command is then joined with the command compiling the driver in the same location with the -cp flag pointing to the current directory. Upon successful compilation, the test driver runs, and the output is captured by the script and then redirected to the HTML file for output. This process repeats until the directory has no more test cases to traverse through, and, at the end of this, the script opens the default browser for the user and displays the outcome for all test cases that were provided at runtime.

For the ease of the viewer, the script also outputs a message for each test case, indicating whether the test case passed or failed. In addition, the script colors the word “PASSED” in green, and “FAILED” in red to increase readability. A sample of the output with both of these events occurring follows below.

```
megan@ubuntu:~/Team-6$ cd TestAutomation
megan@ubuntu:~/Team-6/TestAutomation$ ./scripts/runAllTests.sh
megan@ubuntu:~/Team-6/TestAutomation$
```

Figure 2.1: Running the script from the TestAutomation directory

```
Date and Time Test Ran: 02/12/2020 05:21:40 EST
Test Case ID: TC006
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {10, 50, 20} 25
Expected Result: [50, 20, 25]
Test Result: [50, 20, 25]
Test case PASSED.

Date and Time Test Ran: 02/12/2020 05:21:41 EST
Test Case ID: TC007
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {14} 10
Expected Result: [10]
Test Result: []
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 02/12/2020 05:21:42 EST
Test Case ID: TC008
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {15, 23} 14
Expected Result: [23, 14]
Test Result: [23, 14]
Test case PASSED.

Date and Time Test Ran: 02/12/2020 05:21:44 EST
Test Case ID: TC009
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {2147483647, 0, -1, 2147483647} -2147483648
Expected Result: [0, -1, 2147483647, -2147483648]
Test Result: [0, -1, 2147483647, -2147483648]
Test case PASSED.

Date and Time Test Ran: 02/12/2020 05:21:45 EST
Test Case ID: TC010
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {-2147483648, -5, 0} -2147483648
Expected Result: [-5, 0, -2147483648]
Test Result: [-5, 0, -2147483648]
Test case PASSED.
```

Figure 2.2: Example output from the testing framework with both Pass and Fail

Building OpenMRS

Overall, the documentation made building the project less difficult, but not easy. Once the prerequisite software was installed, the documentation was followed closely, which led to the group being mostly able to build effectively. However, the documentation for building the project was incomplete, as there were missing dependencies, such as Jetty and MySQL, which gave the group some initial troubles. There were also some issues getting Jetty to work with the OpenMRS software. The solution to this was already present in the OpenMRS build commands, as the clean package command installs a Jetty instance for deployment.

There were a number of issues that were faced after the localhost website was running. It required a connection to a MySQL database, which presented a few challenges. First, the OpenMRS software requires access to a root account on the MySQL server. Given that the initial settings on the root account for MySQL by default authenticates on the user trying to access it, the first issue was to change the settings to a password-based authentication and a password for the account. Once that was finished, the OpenMRS building was unable to connect to the server, which presented additional problems. Since all of the software was running on localhost, there was no issue with connection errors. Upon looking through the error logs for the terminal hosting the website, it was found that the time zone on the MySQL server was set to "SYSTEM" time zone, which translated to "EDT," and was unrecognizable, thus the connection was terminated. After changing the time zone to UTC ("UTC"), the website connected properly and worked as intended. Prop data was set up by OpenMRS to emulate proper operation.

All tests were run at the cleaning of the project by the Maven module. As a result, no work was required by the team to run any additional tests to ensure the proper operation of the OpenMRS software.

Log in as a User that has the null role to continue.

OpenMRS Username

Password



Figure 3.1: OpenMRS log-in screen

Developing A Test Plan

After building the project, the team's attention went directly to finding places to test. In the beginning of the project, the immense size of the code base made it very difficult to find places to test effectively, and once the User.java file was found, and methods were determined as viable methods to employ our testing framework on.

Designing and Building the Framework

Once the test plan was finalized and the methods selected, the team set on to develop the framework to test the methods selected in the User.java program. As none of us had any significant experience in Bash, the team elected to use Bash to develop the testing framework. Another significant reason comes at the fact that Bash much more easily interfaces with Git as well as the file structure of a Linux machine. While we evaluated Python to be able to handle these same constructs, in order to have a much easier time in directory traversal, the team found Bash to be much more potent in solving these problems. The team took this as motivation to become much more proficient in Bash, which yielded significant rewards as we were able to gain proficiency with Bash, as well as find resources to be more effective with Bash scripting.

However, as development continued, significant issues plagued the development, primarily the requirement of external dependencies to compile the User.java program. As a result, the team decided to switch to the Thread-Safe Circular FIFO Queue program. This program had no external dependencies, nor any other dependencies in the OpenMRS codebase. This made development of the testing framework significantly easier, as the script was able to locate the file in the project directory and copy into the directory that contains the driver. All of the pertinent information was parsed directly from the test case file that the driver was reading. As a result, we were able to achieve our goals of a functional testing framework much more effectively and development chugged along much smoother.

Another significant challenge that the team faced with regards to developing the framework involved a unique challenge as a result of both Bash and the text editors used to create the test case files. In the parsing of the files, carriage returns at the end of the line was presenting an issue with Bash overwriting the variable value due to the carriage return. Because of this, after the first test case, the framework would not be able to find pertinent files. Through hours of debugging and outputting values with the terminal, the team was able to find the error and correct it, though at a significant time cost to the group.

The most potent challenge that the team faced, however, was the challenge of working virtually due to COVID-19 restrictions. Prior to this semester, the team members had felt very comfortable being able to collaborate in real-time, which made the efforts to develop the framework significantly more difficult. In addition to having to delegate significant tasks through text messages primarily, the challenge in having to be precise and concise with documentation made it much harder to collaborate, particularly as prior classes that had had any collaborative elements were able to work together in person, and the team members had significant trouble adjusting to this new dynamic. One solution that the team elected to employ was delegation of work between team members to work on separate parts of the project to ease the strain of collaborative work. This also presented some severe issues in that every person was responsible for their part and each person had to take the initiative to ask for assistance if there was a blocker. As communication got much better, this issue began to resolve itself.

Extending the Framework

Our experience with this deliverable was somewhat unexpected, as our group had a more difficult time in creating all twenty-five test cases than we had originally thought. Because our first five test cases were already up and running successfully, we assumed that creating twenty more in a similar fashion would be much easier. However, as with any task, things did not always go as planned and we learned very quickly that our assumption was made naively and prematurely. One small challenge that the group ran into was diligently looking through all code documentation to ensure that the correct datatypes were used for test case input and expected output, as several of our test cases involve abstract data types.

Additionally, we faced a problem specific to just one method, `toArray`, and its test cases despite all other test cases for the other tested methods functioning as intended. Although the `toArray` expected outputs and actual outputs of the test cases matched and should have caused all test cases to pass, the results of the test run indicated that the cases had failed. After some research, we found that the problem was likely due to regex-matching within the script, and placing quotations around the variable name, `$expected`, allowed for a simple fix, which allowed the variable to be treated as a string literal, another idiosyncrasy of the Bash scripting language.

However, the positive side to deliverable #4 is that the group continued learning new things and gaining valuable experience. Furthermore, the work progressed at a faster rate than for past deliverables, allowing the group time to fine-tune past deliverables. This included adding a time and date stamp to the testing output file for each time that the `runAllTests.sh` script is run. Our group also worked to better format the output of the test case results so that it is in a neater format that is easier to read and more detailed information is presented for each test case, including the expected output for each test case, the actual output, method being tested, etc. One way that the output is more neatly formatted is the use of color; “PASSED” is colored in green for each test case if the test case output matches the expected output, while “FAILED” is colored red if test case output does not match expected output for the tested method.

In addition, all methods are located within the `ThreadSafeCircularFifoQueue.java` file and are as follows: `toArray`, `add`, `addAll`, `contains`, and `containsAll`.

Each method contains five test cases each, which may be found in the `testCases` directory of the team repository. Each tested method has one driver each, called by the Bash script, `runAllTests.sh`, and the script automatically uses all twenty-five test cases within the testing framework. Like in past deliverables, output from the testing is written into the file `out.html`, which is automatically opened in the default web browser upon completion of running the Bash script.

Date and Time Test Ran: 02/12/2020 05:21:32 EST
Test Case ID: TC001
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: contains
Test Arguments: {3, 1234, 4321, 25} null
Expected Result: false
Test Result: false
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:34 EST
Test Case ID: TC002
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: contains
Test Arguments: {3, 1234, 4321, 25} 43
Expected Result: false
Test Result: false
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:35 EST
Test Case ID: TC003
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: contains
Test Arguments: {3, 1234, 4321, 25} 2344
Expected Result: false
Test Result: false
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:37 EST
Test Case ID: TC004
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: contains
Test Arguments: {3, 1234, 4321, 25} foo
Expected Result: false
Test Result: false
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:38 EST
Test Case ID: TC005
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: contains
Test Arguments: {3, 1234, 4321, 25} 1234
Expected Result: true
Test Result: true
Test case **PASSED**.

Figure 6.1: Test Results of contains method

Date and Time Test Ran: 02/12/2020 05:21:40 EST
Test Case ID: TC006
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {10, 50, 20} 25
Expected Result: [50, 20, 25]
Test Result: [50, 20, 25]
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:41 EST
Test Case ID: TC007
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {14} 10
Expected Result: [10]
Test Result: []
Test case **FAILED**. Result of the test is not the expected result.

Date and Time Test Ran: 02/12/2020 05:21:42 EST
Test Case ID: TC008
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {15, 23} 14
Expected Result: [23, 14]
Test Result: [23, 14]
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:44 EST
Test Case ID: TC009
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {2147483647, 0, -1, 2147483647} -2147483648
Expected Result: [0, -1, 2147483647, -2147483648]
Test Result: [0, -1, 2147483647, -2147483648]
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:45 EST
Test Case ID: TC010
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: add
Test Arguments: {-2147483648, -5, 0} -2147483648
Expected Result: [-5, 0, -2147483648]
Test Result: [-5, 0, -2147483648]
Test case **PASSED**.

Figure 6.2: Test Results of add method

Date and Time Test Ran: 02/12/2020 05:21:47 EST
Test Case ID: TC011
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 48, 20, 57
Expected Result: {48, 20, 57}
Test Result: {48, 20, 57}
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:48 EST
Test Case ID: TC012
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 22, 47, 20, 57
Expected Result: {22, 47, 20, 57}
Test Result: {22, 47, 20, 57}
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:50 EST
Test Case ID: TC013
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 48, 99, 57
Expected Result: {48, 99, 57}
Test Result: {48, 99, 57}
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:51 EST
Test Case ID: TC014
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 8, 11
Expected Result: {8, 11}
Test Result: {8, 11}
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:53 EST
Test Case ID: TC015
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 48, 20, 57, 77, 30
Expected Result: {48, 20, 57, 77, 30}
Test Result: {48, 20, 57, 77, 30}
Test case **PASSED**.

Figure 6.3: Test Results of toArray method

Date and Time Test Ran: 02/12/2020 05:21:54 EST
Test Case ID: TC016
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: addAll
Test Arguments: {930, 37, 109}
Expected Result: true
Test Result: true
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:56 EST
Test Case ID: TC017
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: addAll
Test Arguments: null
Expected Result: true
Test Result: true
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:58 EST
Test Case ID: TC018
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: addAll
Test Arguments: {39, 15, 20}
Expected Result: true
Test Result: true
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:21:59 EST
Test Case ID: TC019
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: addAll
Test Arguments: {499, 105, 175, 200}
Expected Result: true
Test Result: true
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:22:01 EST
Test Case ID: TC020
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: addAll
Test Arguments: {48}
Expected Result: true
Test Result: true
Test case **PASSED**.

Figure 6.4: Test Results of addAll method

Date and Time Test Ran: 02/12/2020 05:22:03 EST
Test Case ID: TC021
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {10, 32, 15} {10, 15}
Expected Result: true
Test Result: true
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:22:04 EST
Test Case ID: TC022
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: null {10}
Expected Result: false
Test Result: false
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:22:06 EST
Test Case ID: TC023
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 4710, 3094} {390, 4709}
Expected Result: false
Test Result: false
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:22:08 EST
Test Case ID: TC024
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 10} null
Expected Result: true
Test Result: true
Test case **PASSED**.

Date and Time Test Ran: 02/12/2020 05:22:09 EST
Test Case ID: TC025
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 40, 10} {390, 40, 10}
Expected Result: true
Test Result: true
Test case **PASSED**.

Figure 6.5: Test Results of containsAll method

Fault Injection Results

After implementing the necessary changes from Deliverable 4, the team set to work finding potential faults in the ThreadSafeCircularFifoQueue.java program. Throughout all of the methods being tested and the associated internal methods that are called by these methods, the following changes to the code will produce the following changes in the test cases, with pictures of the output when that change is triggered.

Change 1 - In line 353, in the toArray method, changing the conditional from "if (result.length > size) {" to "if (result.length >= size) {" will trigger an off-by-one error and populate the final space with a null value in all toArray test cases, causing them all to fail.

```
Date and Time Test Ran: 23/11/2020 22:59:36 EST
Test Case ID: TC011
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 48, 20, 57
Expected Result: {48, 20, 57}
Test Result: {48, 20, null}
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 22:59:41 EST
Test Case ID: TC012
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 22, 47, 20, 57
Expected Result: {22, 47, 20, 57}
Test Result: {22, 47, 20, null}
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 22:59:46 EST
Test Case ID: TC013
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 48, 99, 57
Expected Result: {48, 99, 57}
Test Result: {48, 99, null}
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 22:59:51 EST
Test Case ID: TC014
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 8, 11
Expected Result: {8, 11}
Test Result: {8, null}
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 22:59:56 EST
Test Case ID: TC015
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: toArray
Test Arguments: 48, 20, 57, 77, 30
Expected Result: {48, 20, 57, 77, 30}
Test Result: {48, 20, 57, 77, null}
Test case FAILED. Result of the test is not the expected result.
```

Figure 7.1: Test Results of the first Fault Injection

Change 2 - In line 160, in the containsAll method, changing the logical operator from "||" to "&&" in the conditional will trigger a failed null check in test case 24, which results in a failure for this test case.

Date and Time Test Ran: 23/11/2020 23:11:19 EST
Test Case ID: TC023
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 4710, 3094} {390, 4709}
Expected Result: false
Test Result: false
Test case **PASSED**.

Date and Time Test Ran: 23/11/2020 23:11:24 EST
Test Case ID: TC024
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 10} null
Expected Result: true
Test Result:
Test case **FAILED**. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 23:11:29 EST
Test Case ID: TC025
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 40, 10} {390, 40, 10}
Expected Result: true
Test Result: true
Test case **PASSED**.

Figure 7.2: Test Results of the second Fault Injection

Change 3 - In line 422, in the internalContains method, which is called by both "contains" and "containsAll," changing the ".equals" comparator to the "==" triggers a fault in test cases 5 and 25 only.

Date and Time Test Ran: 30/11/2020 14:55:26 EST

Test Case ID: TC004

File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java

Method Being Tested: contains

Test Arguments: {3, 1234, 4321, 25} foo

Expected Result: false

Test Result: false

Test case **PASSED**.

Date and Time Test Ran: 30/11/2020 14:55:30 EST

Test Case ID: TC005

File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java

Method Being Tested: contains

Test Arguments: {3, 1234, 4321, 25} 1234

Expected Result: true

Test Result: false

Test case **FAILED**. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 23:19:36 EST

Test Case ID: TC023

File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java

Method Being Tested: containsAll

Test Arguments: {390, 4710, 3094} {390, 4709}

Expected Result: false

Test Result: false

Test case **PASSED**.

Date and Time Test Ran: 23/11/2020 23:19:41 EST

Test Case ID: TC024

File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java

Method Being Tested: containsAll

Test Arguments: {390, 10} null

Expected Result: true

Test Result: true

Test case **PASSED**.

Date and Time Test Ran: 23/11/2020 23:19:46 EST

Test Case ID: TC025

File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java

Method Being Tested: containsAll

Test Arguments: {390, 40, 10} {390, 40, 10}

Expected Result: true

Test Result: false

Test case **FAILED**. Result of the test is not the expected result.

Figure 7.3: Test Results of the third Fault Injection

Change 4 - In line 168, removing the negation on the internalContains() method call will cause all containsAll test cases to fail that do not use the null check to bypass checking the array.

```
Date and Time Test Ran: 23/11/2020 23:29:05 EST
Test Case ID: TC021
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {10, 32, 15} {10, 15}
Expected Result: true
Test Result: false
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 23:29:10 EST
Test Case ID: TC022
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: null {10}
Expected Result: false
Test Result: true
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 23/11/2020 23:29:15 EST
Test Case ID: TC023
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 4710, 3094} {390, 4709}
Expected Result: false
Test Result: false
Test case PASSED.

Date and Time Test Ran: 23/11/2020 23:29:20 EST
Test Case ID: TC024
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 10} null
Expected Result: true
Test Result: true
Test case PASSED.

Date and Time Test Ran: 23/11/2020 23:29:24 EST
Test Case ID: TC025
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 40, 10} {390, 40, 10}
Expected Result: true
Test Result: false
Test case FAILED. Result of the test is not the expected result.
```

Figure 7.4: Test Results of the fourth Fault Injection

Change 5 - In line 160, changing the "==" equality operator in "c == null" check to a "!=" equality operator, this causes 3 out of the 5 test cases to fail, interestingly enough, one test case that does not rely on null at all, but passes under normal circumstances.

```
Date and Time Test Ran: 24/11/2020 00:00:31 EST
Test Case ID: TC021
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {10, 32, 15} {10, 15}
Expected Result: true
Test Result: true
Test case PASSED.

Date and Time Test Ran: 24/11/2020 00:00:35 EST
Test Case ID: TC022
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: null {10}
Expected Result: false
Test Result: true
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 24/11/2020 00:00:40 EST
Test Case ID: TC023
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 4710, 3094} {390, 4709}
Expected Result: false
Test Result: true
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 24/11/2020 00:00:45 EST
Test Case ID: TC024
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 10} null
Expected Result: true
Test Result:
Test case FAILED. Result of the test is not the expected result.

Date and Time Test Ran: 24/11/2020 00:00:51 EST
Test Case ID: TC025
File Being Tested: ../project/openmrs-core/api/src/main/java/org/openmrs/util/ThreadSafeCircularFifoQueue.java
Method Being Tested: containsAll
Test Arguments: {390, 40, 10} {390, 40, 10}
Expected Result: true
Test Result: true
Test case PASSED.
```

Figure 7.5: Test Results of the fifth Fault Injection

Overall, this learning experience was one of patience and determination. The codebase that we were working with tended to be scarce at certain points, which made finding potential faults much more difficult for certain methods. As a result, we had to work around those and try to capitalize on certain methods that were a little more substantial. We also tried to emphasize minimal changes that would be common for a programmer who is unfamiliar with the problem or unfamiliar with Java would likely make to determine whether the program was sufficiently redundant to protect against these. Off-By-One errors are very common and in the case highlighted, could potentially cause errors with the list. As well, the switch from "||" to "&&" is a very common mistake, especially with complex data structures, it can be very easy to mix the two up and make an error of this kind, which, as we saw, only triggered one error in one case, which would be significantly hard to detect.

Lessons and Experiences