UNIVERSITY OF MALTA

Introduction of Software Testing

Matthew Drago
441198M

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Contents

1 Dependencies and Structure

The project uses Gradle as it's build system and it is written using Java 10, hence make sure these are installed before compiling the project. This project was built and verified working on Arch Linux.

1.1 Building The Project and Running Tests

Compiling the main sources:

```
bash gradlew compileJava
```

Invoking all tests:

```
bash gradlew test
```

Should you require more detail on what each method does you can also generate the Java Doc from gradle:

```
bash gradlew test
```

The Java Doc should be found under build/docs/javadoc.

1.2 Structure

1.2.1 Java Sources

The project sources lie under com.cps3230.assignment.payment, which contain two packages gateway and webapp. The Gateway package houses the backend of the project, including the Payment Processor and is where Tasks 1 and 2 are located. The webapp package houses a Spring Boot application with an embedded server. (Required for Task 3)

Package	Description
gateway.constants	Contains classes representing constant values;
gateway.enums	Contains enums such as Card Brands and Transaction States;
gateway.interfaces	Contains interfaces used by the gateway;
gateway.utils	Contains utility classes;

Figure 1: A brief description of packages in the Gateway package

1.2.2 Test Sources

The test sources use the same package structure as mentioned before.

Package	Description
gateway.adaptors	Contains abstractions for the ModelJUnit testing suite;
gateway.helpers	Contains helper classes that enhance the Testing suite;
gateway.models	Contains Models used by the ModelJUnit testing suite;
gateway.stubs	Contains Stubbed classes;
webapp.pageobjects	Contains PageObjects that abstract Selenium functions;
webapp.stepdefs	Contains gherkin definition classes;
webapp.utils	Contains helper classes;

Figure 2: A brief description of packages in the Gateway package

2 Unit Testing Task

2.1 Parameterised Tests

This project heavily uses JUnit5's Parameterised Tests to write concise repeatable tests. A Parameterised Test is similar to a normal test but is run with different arguments. Example the test case checkLuhnWorksCorrectlyWithValidCards will run 5 times, each with a different valid card number.

The alternative would be to write five different test cases testing exactly the same thing but passing a different value.

Listing 1: A Parameterised Test using a Value Source

```
@ParameterizedTest
@ValueSource(strings = {"371449635398431", "4230␣6885␣1339␣5737", "3404␣769161␣31932",
 "4024␣0071␣5598␣4809", "5423␣5299␣5706␣1290"})
void checkLuhnWorksCorrectlyWithValidCards(String creditCards) {
   Assertions.assertTrue(processor.verifyLuhn(creditCards),
   String.format("Card␣number␣%s␣should␣be␣valid", creditCards));
}
```

Arguments can be also passed through an other helper method and using the annotation @MethodSource. Method sources should return a steam of arguments. Example the following snippet tests the processPayment function whilst passing a CcInfo object with a combination of invalid card types and card numbers with invalid prefixes and or lengths.

Listing 2: An example of a method source

```
private static Stream<Arguments> generateCreditCardDetailsWithInvalidCardTypesAndPrefixes() {
   return Stream.of(
      Arguments.of(new CcInfo("Test␣User", "", "AMERICAN_EXPRESS", "371449635398431", "10/20", "111")),
      Arguments.of(new CcInfo("Test␣User", "Test␣address", "amer", "371449635398431", "10/20", "111")),
      Arguments.of(new CcInfo("Test␣User", "Test␣address", "VISA", "371449635398431", "10/20", "111")),
      Arguments.of(new CcInfo("Test␣User", "Test␣address", "VISA", "5286529599000892", "10/20", "111"))
   );
}
```

Listing 3: An example of a test case recieving a method source

```
@ParameterizedTest
@MethodSource("generateCreditCardDetailsWithInvalidCardTypesAndPrefixes")
void checkProcessPaymentVerifiesCreditCardDetailsWithInvalidCardTypeAndCardNumber(CcInfo card)
   throws ExecutionException, InterruptedException {
   DateIn2018Stub date = new DateIn2018Stub();
   Assertions.assertEquals(1, processor.processPayment(card, 10, date.getTime()));
}
```

2.2 Test Doubles

The test suite makes heavy use of test doubles most notably Stubs, Spies and Mocks.

2.2.1 Stubs

The test suite contains two stubs: DateIn2018Stub and DateIn2021. These stubs return a date in 2018 and 2021 respectively and are used in the Verify Offline method. The class extends from GregorianCalendar and overrides the constructor to explicitly set the date value.

Listing 4: The DateIn2018Stub

```
public class DateIn2018Stub extends GregorianCalendar
    {
   public DateIn2018Stub() {
      set(Calendar.MONTH, 3);
      set(Calendar.YEAR, 2018);
   }
}
```

The Verify Offline method's signature had to be changed to accept a date to compare to. This way the stub can be injected into the method from the test suite. For convenience the method was overloaded to accept card info and automatically passes today's date.

Listing 5: The Verify Offline method signature

```
public CardValidationStatuses verifyOfflineEnum(CcInfo
     cardInfo, Date date) {
   ...
```

Listing 6: The overloaded Verify Offline method

```
public CardValidationStatuses verifyOfflineEnum(CcInfo
     cardInfo) {
   return verifyOfflineEnum(cardInfo, new Date());
}
```

Listing 7: An example of a test using a stub

```
@ParameterizedTest
@ValueSource(strings = {"7992739I871o", "79927398712",
     "79927398719"})
void checkOfflineVerificationWithInvalidCardNumbers(
    String cardNumber) {
  DateIn2018Stub date = new DateIn2018Stub();
  CcInfo testCreditCardDetails =
     new CcInfo("Test␣User", "Test␣address", "
         AMERICAN_EXPRESS", cardNumber, "10/20",
        "111");
  Assertions.assertEquals(1, processor.verifyOffline(
      testCreditCardDetails, date.getTime()));
}
```

Hadn't stub been used, the test suite would have to be altered every couple of years as cards that wouldn't have been expired would eventually expire, making the tests fail. This stub ensures the tests are repeatable over time.

2.3 Spies

Spies are extended stubs as the provide the same features as stubs whilst also checking the interactions between the stubbed object. The traditional spies are used to verify interactions between the database and the process payment method. This was used to verify interactions between payment processor and and the Transaction Database.

Listing 8: "Using the database spy in the test suite"

```java
@Test
void
    verifyTheTransactionDatabaseIsAccessedWhenPaymentAuthorized
    ()
   throws ExecutionException, InterruptedException {
  DatabaseSpy databaseSpy = new DatabaseSpy();
  ...
  processor.setConnection(databaseSpy);
  processor.processPayment(testCard, 10, date.getTime()
      );
  Assertions.assertTrue(databaseSpy.isAccessed(), "
      Transaction␣should␣be␣accessed");
}
```

Listing 9: The database spy impmplemention

```java
public class DatabaseSpy implements DatabaseConnection
     {

   private Map<Long, Transaction> database;

   private int requestCount;

   public DatabaseSpy() {
      database = new HashMap<>();
      requestCount = 0;
   }

   @Override
   public boolean saveTransaction(Transaction
       transaction) {
      database.put(transaction.getId(), transaction);
      requestCount++;
      return true;
   }

   @Override
   public Map<Long, Transaction> getDatabase() {
      return database;
```

```java
    }

    public int getRequestCount() {
        return requestCount;
    }

    public boolean isAccessed() {
        return requestCount > 0;
    }
}
```

This project also uses Mockito's spy functionality to verify the interactions between certain objects. This works by mocking the object of interest and then calling the verify method from Mockito. If the method was not called it throws an assertion exception and the test fails.

Listing 10: Using mockito to spy on the bank proxy

```java
@Test
void
    checkIfBankProxyAuthIsBeingCalledFromProcessPayment
    ()
    throws ExecutionException, InterruptedException {
  BankProxy proxy = spy(BankProxy.class);
  DateIn2018Stub date = new DateIn2018Stub();
  CcInfo testCard = new CcInfo("Test␣User", "test␣
      address", "AMERICAN_EXPRESS", "371449635398431",
      "10/20", "111");
  processor.setBankProxy(proxy);
  processor.processPayment(testCard, 10, date.getTime()
      );
  verify(proxy).auth(testCard, 10);
}
```

2.3.1 Mocks

Mock objects combine the benefits of stubs and spies whilst also verify SUT behaviour. They are heavily used in the test suite and are created using mockito. Since the BankProxy class will be provided by the bank, it had to be mocked to verify the payment processor.

```java
@Test
void
    checkProcessPaymentFailsWhenAuthorisationFailsBecauseBankDetailsInvalid
    ()
    throws ExecutionException, InterruptedException {
    DateIn2018Stub date = new DateIn2018Stub();
    BankProxy proxy = mock(BankProxy.class);
    CcInfo testCard = new CcInfo("Test␣User", "test␣
        address", "AMERICAN_EXPRESS", "371449635398431"
        ,
      "10/20", "111");
    when(proxy.auth(testCard, 10)).thenReturn((long)-1);
    processor.setBankProxy(proxy);
    Assertions.assertEquals(2, processor.processPayment(testCard, 10, date.getTime()));
}
```

Mocks where also used to simulate a late response from the database proxy.

Listing 11: Delaying responses from bank proxy

```
when(proxy.capture( 111)).thenAnswer(new Answer<Long>() {
    @Override
    public Long answer(InvocationOnMock invocation) throws InterruptedException {
        Thread.sleep(2000);
        return (long) 0;
    }
});
```

2.4 Deviation from the Specification

Some changes to the specification where made to increase code quality, and to make the source more testable.

2.4.1 Transaction Database

A Database connection interface was created in order for the payment processor to accept the database test spy. The payment processor also has a special getter that automatically initializes a transaction database if it's null, thus avoiding any Null Pointer Exceptions. Data sources should extend this interface to integrate with the payment processor.

```
public interface DatabaseConnection {
    boolean saveTransaction(Transaction transaction);
    Map<Long, Transaction> getDatabase();
}
```

For simplicity the transaction database was implemented using a Hash Map.

```
public class TransactionDatabase implements DatabaseConnection {

    Map<Long, Transaction> database;

    TransactionDatabase() {
        database = new HashMap<>();
    }
    ...
```

2.4.2 CcInfo

The CcInfo class holds information related to card details. Some modifications where made to include most of the verification code in the getters and setters of CcInfo. Example an invalid date or card would not be allowed to be set. It also has some helper functions related to card detail verification. This allows each function to be tested individually from the CcInfoTests class.

```java
public boolean setCardExpiryDate(String cardExpiryDate
    ) {
   boolean valid = true;
   SimpleDateFormat simpleDateFormat = new
       SimpleDateFormat("mm/YY");
   simpleDateFormat.setLenient(false);
   try {
      simpleDateFormat.parse(cardExpiryDate);
      this.cardExpiryDate = cardExpiryDate.replaceAll(
          "\\s+", "");
   } catch (ParseException e) {
      valid = false;
   }
   return valid;
}
```

Listing 12: A helper function that checks the card prefixes

```java
protected boolean validatePrefix() {
   boolean validity = false;
   if (CardLengths.getCardLengths().get(
       getCardTypeEnum())
      .contains(getCardNumber().length()) &&
          CardPrefixes.validPrefixes().get(
          getCardTypeEnum())
      .contains(getCardNumberPrefix())) {
     validity = true;
   }
   return validity;
}
```

2.4.3 Payment Processor

The specifications for payment processor mentions three methods, namely processPayment, verifyOffline and verifyLuhn. The verify luhn method has not changed from the specification. The verify offlineMethod is simply a wrapper to another method, verifyOfflineEnum which returns an enum representation of the error message. It does not make sense to test some of these overloaded methods as they just call the main verifyOfflineEnum method and pass some default parameters.

Listing 13: Verify offline overloaded methods

```java
public int verifyOffline(CcInfo cardInfo) {
   return verifyOfflineEnum(cardInfo, new Date()).
       ordinal();
}

public int verifyOffline(CcInfo cardInfo, Date date) {
   return verifyOfflineEnum(cardInfo, date).ordinal();
}

// The verify offline method where the main processing
     is done.
public CardValidationStatuses verifyOfflineEnum(CcInfo
     cardInfo, Date date) {
   CardValidationStatuses cardValidityStatus =
       CardValidationStatuses.VALID;
   if (!cardInfo.verifyAllDetailsAreEntered()) {
      cardValidityStatus = CardValidationStatuses.
          EMPTY_FIELDS;
   } else if (!verifyLuhn(cardInfo.getCardNumber())) {
      cardValidityStatus = CardValidationStatuses.
          LUHN_FAILURE;
   } else if (cardInfo.getCardTypeEnum() == CardBrands
       .INVALID) {
      cardValidityStatus = CardValidationStatuses.
          CARD_BRAND_NOT_VALID;
   } else if (!cardInfo.validatePrefix()) {
      cardValidityStatus = CardValidationStatuses.
          PREFIX_NOT_VALID;
   } else if (cardInfo.validateCardIsNotExpired(date)
       == CardValidationStatuses.CARD_EXPIRED) {
      cardValidityStatus = CardValidationStatuses.
          CARD_EXPIRED;
   }
   return cardValidityStatus;
}
```

Process Payment This method's signature was changed drastically. The method executes requests to the payment processor asynchronously thus it accepts an Executor service to which it latches asynchronous methods to. Once a transaction gets authorized it is saved on to the database and it's status is saved as *CAPTURE*. Every time the processor is called it calls another asynchronous method that tries to capture all transactions in the *CAPTURE* state. However there is a processPayment method whose signature matches with the specification. The process payment relies on two wrapper functions, one that authorizes a transaction and an other that captures a transaction by calling their respective methods in the bank proxy.

Listing 14: A wrapper function that calls the bankporxy asynchronously and returns a Transaction if valid

```java
private Callable<Transaction> authoriseCallable(CcInfo cardInfo, long amount) {
    return () -> {
      Transaction transaction = null;
      long transactionId = getBankProxy().auth(cardInfo, amount);
      if (transactionId > 0) {
        transaction = new Transaction(transactionId, cardInfo, amount, TransactionStates.CAPTURE);
      } else {
        LOGGER.info("Bank␣error␣-␣bank␣returned␣status␣code␣{}␣-␣payment␣rejected", transactionId);
      }
      return transaction;
    };
}
```

Listing 15: A wrapper method that calls the bank proxy asynchronously and

```java
Callable<Transaction> captureCallable(Transaction transaction) {
    return () -> {
        int status = getBankProxy().capture(transaction.getId());
        switch (status) {
            case 0: {
                transaction.setState(TransactionStates.CAPTURED.toString());
                break;
            }
            case -1: {
                transaction.setState(TransactionStates.BANK_DETAILS_INVALID.toString());
                break;
            }
            case -2: {
                transaction.setState(TransactionStates.CAPTURED.toString());
                break;
            }
            case -3: {
                transaction.setState(TransactionStates.VOID.toString());
                break;
            }
            default: {
                transaction.setState(TransactionStates.AUTHORIZED.toString());
            }
        }
```

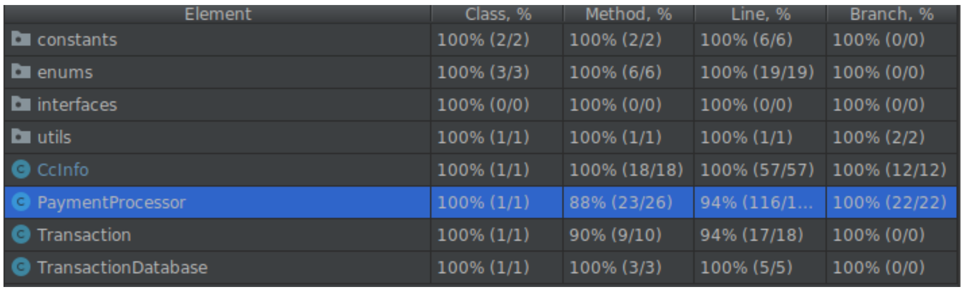
```
            return transaction;
        };
    }
```

2.4.4 Update Database Transactions

Since *AUTHORIZED* transactions get saved in the database a function was created that periodically gets all transactions with an *AUTHORIZED* state and tries to capture them. This method can then be called with a scheduled executor and run periodically.

```
    Callable<Void> updateTransactions(ExecutorService
         executorService, CountDownLatch latch) {
        return () -> {
          Map<Long, Transaction> authorizedTransactions =
               getConnection().getDatabase()
              .entrySet().stream()
              .filter(x -> x.getValue().getState().equals(
                   TransactionStates.AUTHORIZED.toString()))
              .collect(
                  Collectors.toMap(Map.Entry::getKey, Map.
                       Entry::getValue));
          authorizedTransactions.forEach((transId,
               transaction) -> {
            try {
              Future<Transaction> captureFuture =
                   executorService.submit(captureCallable(
                   transaction));
              Transaction capturedTransaction = captureFuture
                   .get();
              getConnection().saveTransaction(
                   capturedTransaction);
            } catch (InterruptedException |
                 ExecutionException e) {
              LOGGER.error(e.getLocalizedMessage());
            }
          });
          latch.countDown();
          return null;
        };
    }
```

2.5 Coverage



Element	Class, %	Method, %	Line, %	Branch, %
constants	100% (2/2)	100% (2/2)	100% (6/6)	100% (0/0)
enums	100% (3/3)	100% (6/6)	100% (19/19)	100% (0/0)
interfaces	100% (0/0)	100% (0/0)	100% (0/0)	100% (0/0)
utils	100% (1/1)	100% (1/1)	100% (1/1)	100% (2/2)
CcInfo	100% (1/1)	100% (18/18)	100% (57/57)	100% (12/12)
PaymentProcessor	100% (1/1)	88% (23/26)	94% (116/1...	100% (22/22)
Transaction	100% (1/1)	90% (9/10)	94% (17/18)	100% (0/0)
TransactionDatabase	100% (1/1)	100% (3/3)	100% (5/5)	100% (0/0)

Figure 3: The overall test coverage

Because of the overloaded methods 100% line coverage could not be achieved, however 95% coverage in the PaymentProcessor is acceptable. It should be noted that the test suite has 100% branch coverage. This means every decision in the code base was hit from the test suite at least once. There was one getter method in the Transaction class that only does simple assignment which was not tested. In general simple getters and setters were not tested individually but were called from other methods in the source. Getters and setters were only tested if they carried out logic. All other classes feature 100% line, class, method and branch coverage.

3 Model Testing

The model tests can be run by running the TransactionModelTest class and are run automatically when you run the test task from gradle. There are three tests the first being runModelTestsWithGreedyTester which executes the model test using a greedy tester. The second test is a unit test that uses an all round tester and the third launches an all round tester. During experimentation it was discovered that the greedy tester works best, hence it's the only test that runs by default whilst the others are ignored. The greedy tester achieves 100% action, state and transition coverage with a test length of 150.

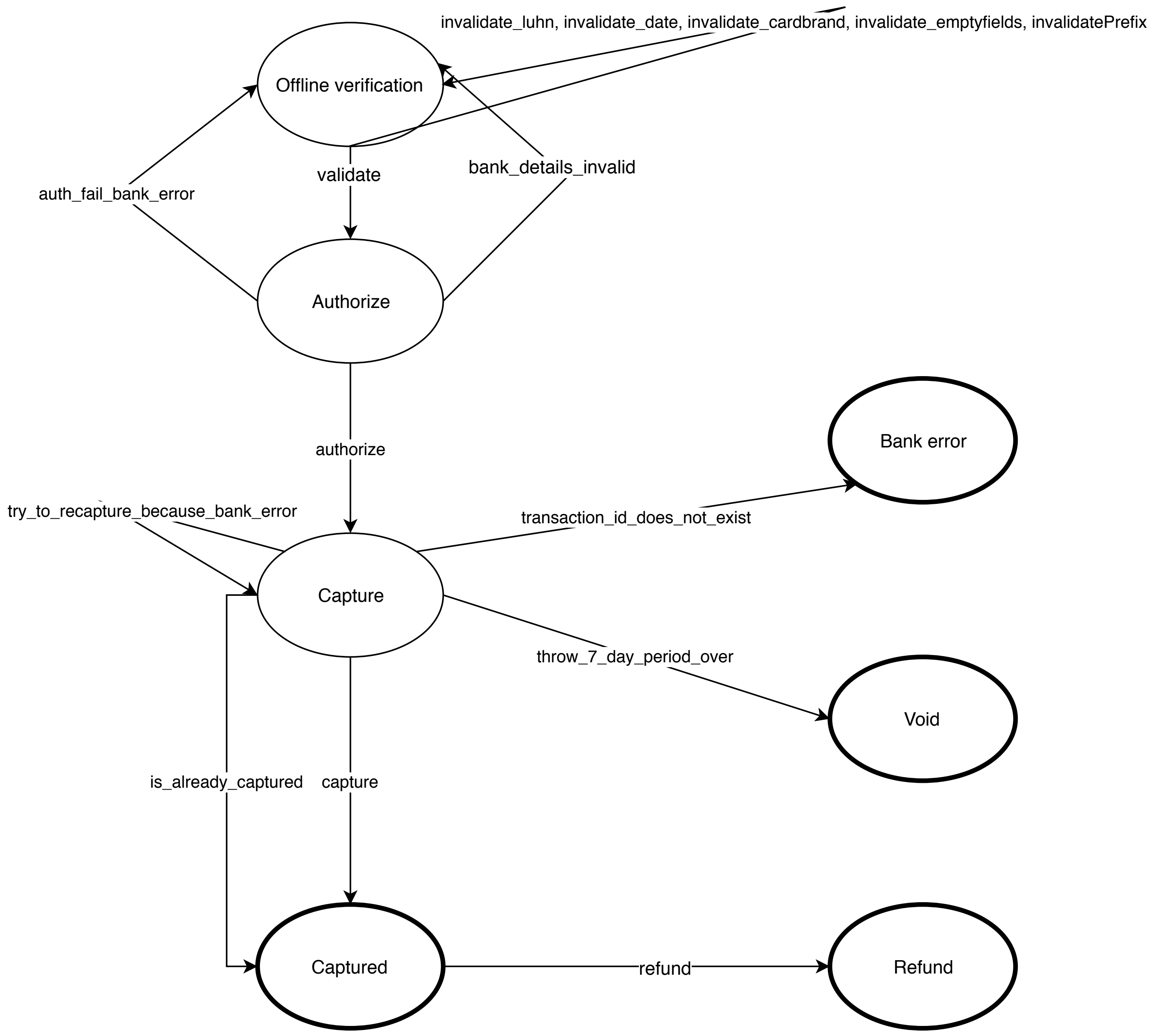
```
    @Test
    void runModelTestsWithGreedyTester() {
        TransactionModel model = new TransactionModel();
        Tester tester = new GreedyTester(model);
        tester.buildGraph();
        tester.addListener(new VerboseListener());
        tester.addListener(new StopOnFailureListener());
        tester.addCoverageMetric(new TransitionCoverage());
        tester.addCoverageMetric(new StateCoverage());
        tester.addCoverageMetric(new ActionCoverage());
        tester.generate(100);
        tester.printCoverage();
    }
```

The Transaction model also makes use of a PaymentProcessorAdaptor that abstracts some of the detail in calling the payment processor and avoid cluttering up the model.

Listing 16: A snippet showing how some of the abstraction is done

```
    public Transaction tryToRecaptureBecauseBankError() throws
         ExecutionException, InterruptedException {
        CcInfo testCreditCardDetails = new CcInfo("Test␣User", "
            Test␣address", "AMERICAN_EXPRESS", "371449635398431",
             "10/20", "111");
        BankProxy mockProxy = mock(BankProxy.class);
        when(mockProxy.capture((long) 111)).thenReturn(-4);
        processor.setBankProxy(mockProxy);
        Transaction transaction = new Transaction((long) 111,
            testCreditCardDetails, 10, "AUTHORIZED");
        return processor.capture(transaction);
    }
```

The following page includes a diagram of the model.



invalidate_luhn, invalidate_date, invalidate_cardbrand, invalidate_emptyfields, invalidatePrefix
Offline verification
auth_fail_bank_error
validate
bank_details_invalid
Authorize
authorize
Bank error
try_to_recapture_because_bank_error
transaction_id_does_not_exist
Capture
throw_7_day_period_over
Void
is_already_captured
capture
Captured
refund
Refund

4 Cucumber and Automated Web Testing

The web interface was implemented using Spring Boot and can be found in the com.cps3230.assignment.payment.webapp package. The cucumber feature files are located under test/resources/features. Spring Boot was used as the web framework as it bundles it's own server thus making it easy to get a web service up and running. Running the server from the command line without mocks:

```
bash gradlew bootRun
```

Note Due to an internal tomcat bug, web tests might fail because an exception is thrown during server shutdown despite the cumber tests passing.

```
bash gradlew test --tests "com.cps3230.assignment.payment.
    webapp.PaymentProcessorWebTests"
```

During the test task a server is run with a mocked Bank Proxy.

4.1 Browser Driver

The Browser Driver is a singleton class that returns a Web driver instance.

Listing 17: Getting a Web Driver Instance

```java
public synchronized static WebDriver getCurrentDriver() {
   if (mDriver == null) {
      try {
         System.setProperty("webdriver.chrome.driver", "/
             home/drago/chromedriver");
         mDriver = new ChromeDriver();
      } finally {
         Runtime.getRuntime().addShutdownHook(
            new Thread(new BrowserCleanup()));
      }
   }
   return mDriver;
}
```

4.2 Page objects

Page objects abstract selenium calls that interact with the webpage. The project implemented the Page Object pattern in the Payment Webapp Page Object class. It contains functions for entering details in the form, submitting the form getting entered information etc...

Listing 18: A method in the Payment Webapp Page Object that facilitates form entry

```
    public void enterDetails(EntryObject entry) {
        driver.findElement(By.name("customerName")).sendKeys(
            entry.getCustomerName());
        driver.findElement(By.name("customerAddress")).
            sendKeys(entry.getCustomerAddress());
        final Select selectBox = new Select(driver.findElement
            (By.name("cardType")));
        selectBox.selectByValue(entry.getCardType());
        driver.findElement(By.name("cardNumber")).sendKeys(
            entry.getCardNumber());
        driver.findElement(By.name("cardExpiryDate")).sendKeys
            (entry.getCardExpiryDate());
        driver.findElement(By.name("cardCvv")).sendKeys(entry.
            getCardCvv());
        driver.findElement(By.name("amount")).sendKeys(entry.
            getAmount());
    }
```

4.3 Cucumber

To be able to inject a mocked Bank proxy the cucumber tests are launched through a Spring Boot Test. This allows the controller to be wired up. The class PaymentProcessorWebTests launches the cucumber tests.

Listing 19: The unit test that launches the cucumber tests

```
    @Test
    public void runCucumberTests() {
        cucumber.api.cli.Main.main(new String[]{
            "--glue",
            "com.cps3230.assignment.webapp.stepdefs",
            "src/test/resources/features/webapp_features.
                feature"
        });
    }
```

The WebappDefs class defines all of the step definitions that are required by the feature files.

Listing 20: A step definition using a cucumber expressions

```
    @When("I␣submit␣a␣form␣with␣all␣data␣but␣{string}␣is␣
        invalid")
    public void submitAFormWithAllDataButIsInvalid(String
        date) throws InterruptedException {
      EntryObject entry = new EntryObject("Test␣User", "Test␣
          Address", "AMERICAN_EXPRESS", "371449635398431",
          date, "111", "10");
      webappPageObject.enterDetails(entry);
      webappPageObject.submitDetails();
    }
```