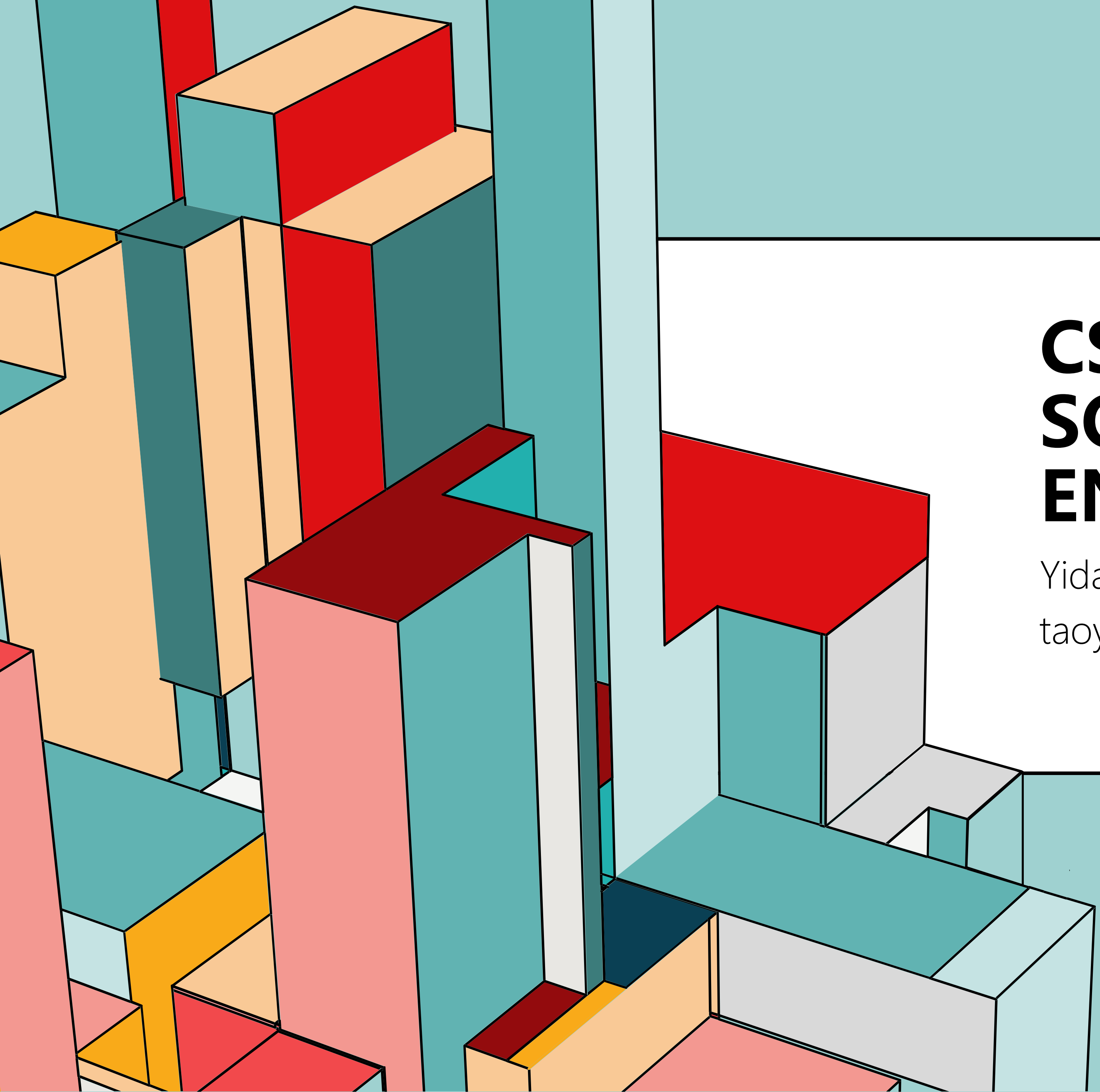
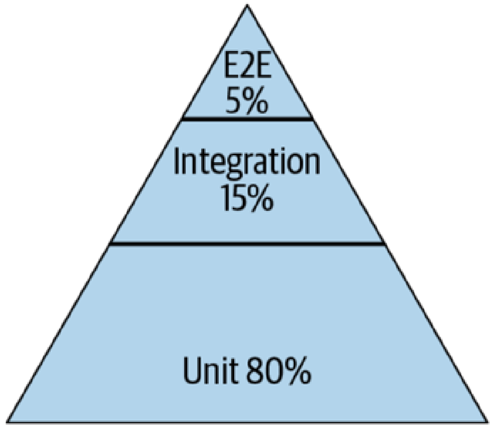


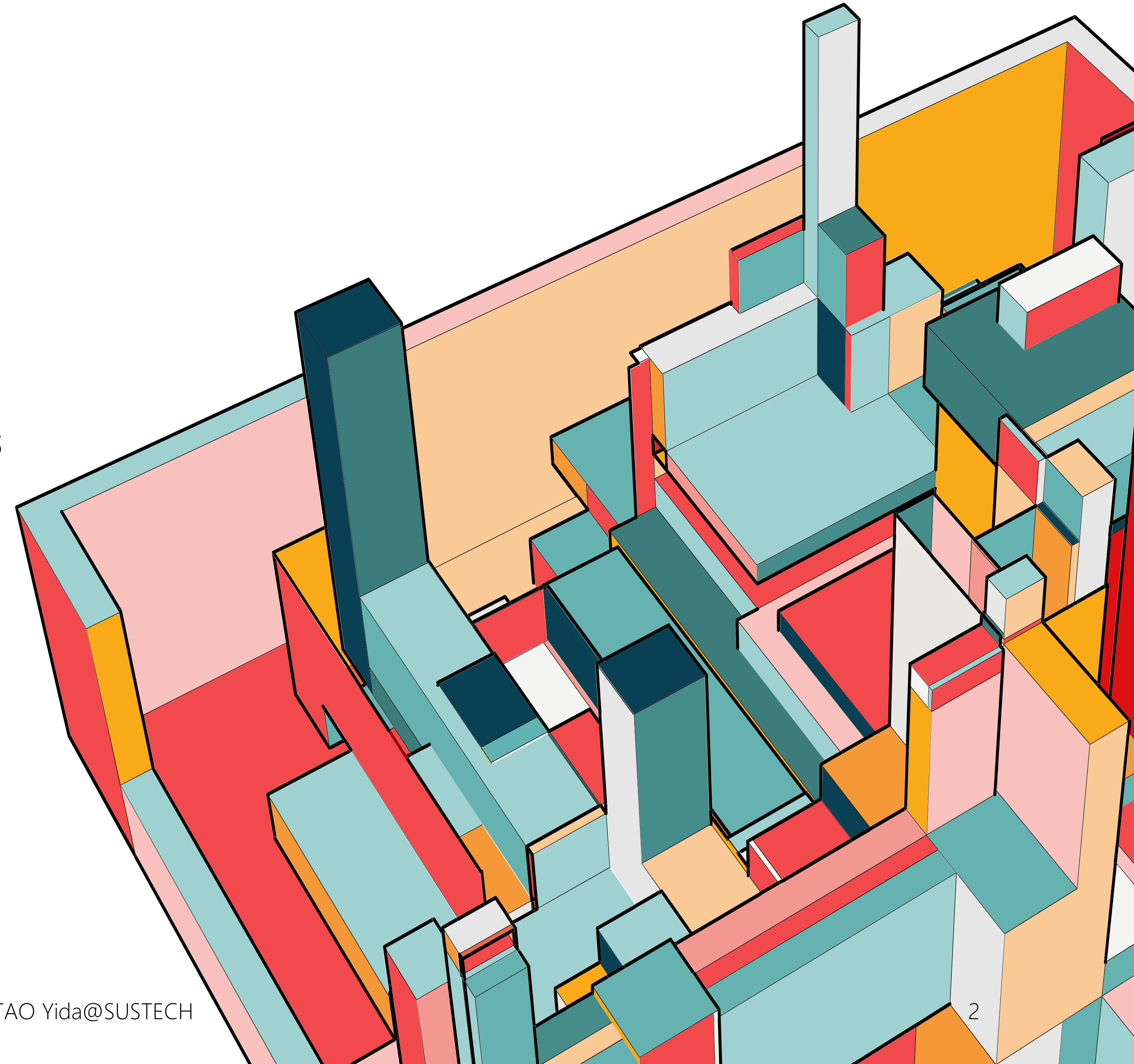
CS304 SOFTWARE ENGINEERING

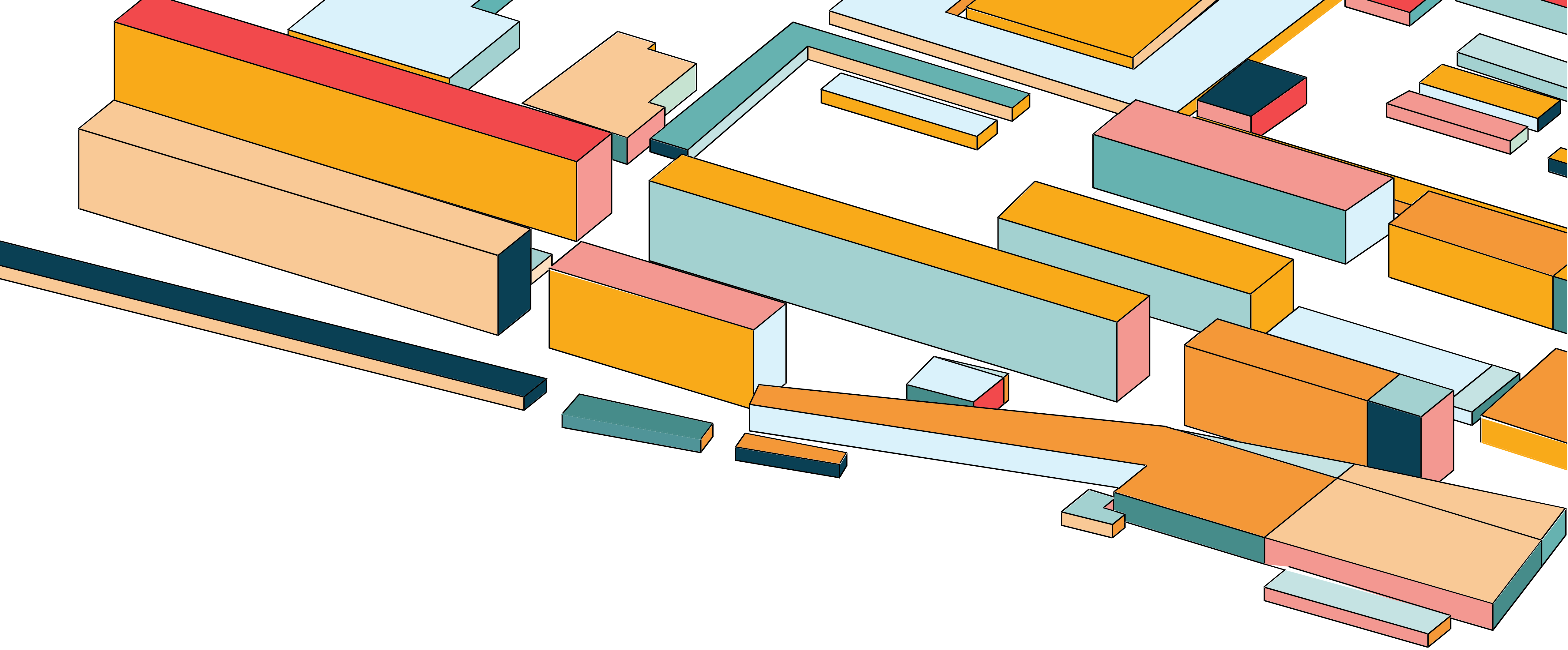
Yida Tao
taoyd@sustech.edu.cn

LECTURE 9

- Maintainable Unit Tests
- Integration tests: Test Doubles
- UI Testing







MAINTAINABLE UNIT TESTS

ULTIMATE GOAL: UNCHANGING TESTS

- Ideally, after a test is written, it never needs to change unless the requirements of the system under test change

- Maintainable tests “just work”: after writing them, engineers don’t need to think about them again until they fail, and those failures indicate real bugs with clear causes.

ULTIMATE GOAL: UNCHANGING TESTS

After writing a test, you shouldn't need to touch that test again as you refactor the system, fix bugs, or add new features.

Refactorings: refactorings don't change the systems' behaviors, existing tests should remain unaffected
New features: new features may require new tests, but existing tests should remain unaffected
Bug fixes: like new features, may require new tests, but existing tests should remain unaffected

Only changing the system's existing behavior would require the updates to existing tests

GOOD PRACTICE 1: TEST VIA PUBLIC APIS

- Public APIs are exposed to users
- Hence, testing public APIs mimic how users use the system

- Public APIs change much less frequently than internal implementations
- Hence, tests on public APIs change less frequently (more maintainable)

BAD PRACTICE

Example 12-1. A transaction API

```
public void processTransaction(Transaction transaction) {
  if (isValid(transaction)) {
    saveToDatabase(transaction);
  }
}

private boolean isValid(Transaction t) {
  return t.getAmount() < t.getSender().getBalance();
}

private void saveToDatabase(Transaction t) {
  String s = t.getSender() + “,” + t.getRecipient() + “,” + t.getAmount();
  database.put(t.getId(), s);
}

public void setAccountBalance(String accountName, int balance) {
  // Write the balance to the database directly
}

public void getAccountBalance(String accountName) {
  // Read transactions from the database to determine the account balance
}
```

BAD PRACTICE

```java
@Test
public void emptyAccountShouldNotBeValid() {
  assertThat(processor.isValid(newTransaction().setSender(EMPTY_ACCOUNT)))
      .isFalse();
}
```

Test the internal (private) implementation logic directly.

This is NOT how real users would use the system

Example 12-1. *A transaction API*

```java
public void processTransaction(Transaction transaction) {
  if (isValid(transaction)) {
    saveToDatabase(transaction);
  }
}

private boolean isValid(Transaction t) {
  return t.getAmount() < t.getSender().getBalance();
}

private void saveToDatabase(Transaction t) {
  String s = t.getSender() + "," + t.getRecipient() + "," + t.getAmount();
  database.put(t.getId(), s);
}

public void setAccountBalance(String accountName, int balance) {
  // Write the balance to the database directly
}

public void getAccountBalance(String accountName) {
  // Read transactions from the database to determine the account balance
}
```

BAD PRACTICE

```
@Test
public void shouldSaveSerializedData() {
  processor.saveToDatabase(newTransaction()
      .setId(123)
      .setSender("me")
      .setRecipient("you")
      .setAmount(100));
  assertThat(database.get(123)).isEqualTo("me,you,100");
}
```

✗

Test the internal states of the database.

Almost any refactoring of the system will cause these tests to break, even if they are invisible to the users.

- Renaming `isValid()`
- Changing how String s is constructed in `saveToDatabase()`

Example 12-1. A transaction API

```
public void processTransaction(Transaction transaction) {
  if (isValid(transaction)) {
    saveToDatabase(transaction);
  }
}

private boolean isValid(Transaction t) {
  return t.getAmount() < t.getSender().getBalance();
}

private void saveToDatabase(Transaction t) {
  String s = t.getSender() + "," + t.getRecipient() + "," + t.getAmount();
  database.put(t.getId(), s);
}

public void setAccountBalance(String accountName, int balance) {
  // Write the balance to the database directly
}

public void getAccountBalance(String accountName) {
  // Read transactions from the database to determine the account balance
}
```

TEST VIA PUBLIC APIS

```
@Test
public void shouldTransferFunds() {
  processor.setAccountBalance("me", 150);
  processor.setAccountBalance("you", 20);

  processor.processTransaction(newTransaction()
      .setSender("me")
      .setRecipient("you")
      .setAmount(100));

  assertThat(processor.getAccountBalance("me")).isEqualTo(50);
  assertThat(processor.getAccountBalance("you")).isEqualTo(120);
}
```

√

The test access the system in the same manner as the users would via public APIs

Example 12-1. A transaction API

```
public void processTransaction(Transaction transaction) {
  if (isValid(transaction)) {
    saveToDatabase(transaction);
  }
}

private boolean isValid(Transaction t) {
  return t.getAmount() < t.getSender().getBalance();
}

private void saveToDatabase(Transaction t) {
  String s = t.getSender() + "," + t.getRecipient() + "," + t.getAmount();
  database.put(t.getId(), s);
}

public void setAccountBalance(String accountName, int balance) {
  // Write the balance to the database directly
}

public void getAccountBalance(String accountName) {
  // Read transactions from the database to determine the account balance
}
```

TEST VIA PUBLIC APIS

```
@Test
public void shouldTransferFunds() {
  processor.setAccountBalance(“me”, 150);
  processor.setAccountBalance(“you”, 20);

  processor.processTransaction(newTransaction()
      .setSender(“me”)
      .setRecipient(“you”)
      .setAmount(100));

  assertThat(processor.getAccountBalance(“me”)).isEqualTo(50);
  assertThat(processor.getAccountBalance(“you”)).isEqualTo(120);
}
```

- Such tests are more realistic and less brittle/more maintainable
- Internal refactoring won’t affect the tests

Example 12-1. A transaction API

```
public void processTransaction(Transaction transaction) {
  if (isValid(transaction)) {
    saveToDatabase(transaction);
  }
}

private boolean isValid(Transaction t) {
  return t.getAmount() < t.getSender().getBalance();
}

private void saveToDatabase(Transaction t) {
  String s = t.getSender() + “,” + t.getRecipient() + “,” + t.getAmount();
  database.put(t.getId(), s);
}

public void setAccountBalance(String accountName, int balance) {
  // Write the balance to the database directly
}

public void getAccountBalance(String accountName) {
  // Read transactions from the database to determine the account balance
}
```

GOOD PRACTICE 2: TEST BEHAVIORS, NOT METHODS

- Common patten: every production method has a corresponding `@test` method
- Convenient at first
- But as the method grow more complex, the test also grows in complexity and becomes less maintainable

TEST BEHAVIORS, NOT METHODS

```
public void displayTransactionResults(User user, Transaction transaction) {
  ui.showMessage("You bought a " + transaction.getItemName());
  if (user.getBalance() < LOW_BALANCE_THRESHOLD) {
    ui.showMessage("Warning: your balance is low!");
  }
}
```

The method to be tested

```
@Test
public void testDisplayTransactionResults() {
  transactionProcessor.displayTransactionResults(
      newUserWithBalance(
          LOW_BALANCE_THRESHOLD.plus(dollars(2))),
      new Transaction("Some Item", dollars(3)));

  assertThat(ui.getText()).contains("You bought a Some Item");
  assertThat(ui.getText()).contains("your balance is low");
}
```

✗

A method-driven test:
As the method under test becomes more complex and implements more functionality, its unit test will become increasingly convoluted and grow more and more difficult to work with.

TEST BEHAVIORS, NOT METHODS

```
public void displayTransactionResults(User user, Transaction transaction) {
  ui.showMessage(“You bought a ” + transaction.getItemName());
  if (user.getBalance() < LOW_BALANCE_THRESHOLD) {
    ui.showMessage(“Warning: your balance is low!”);
  }
}
```

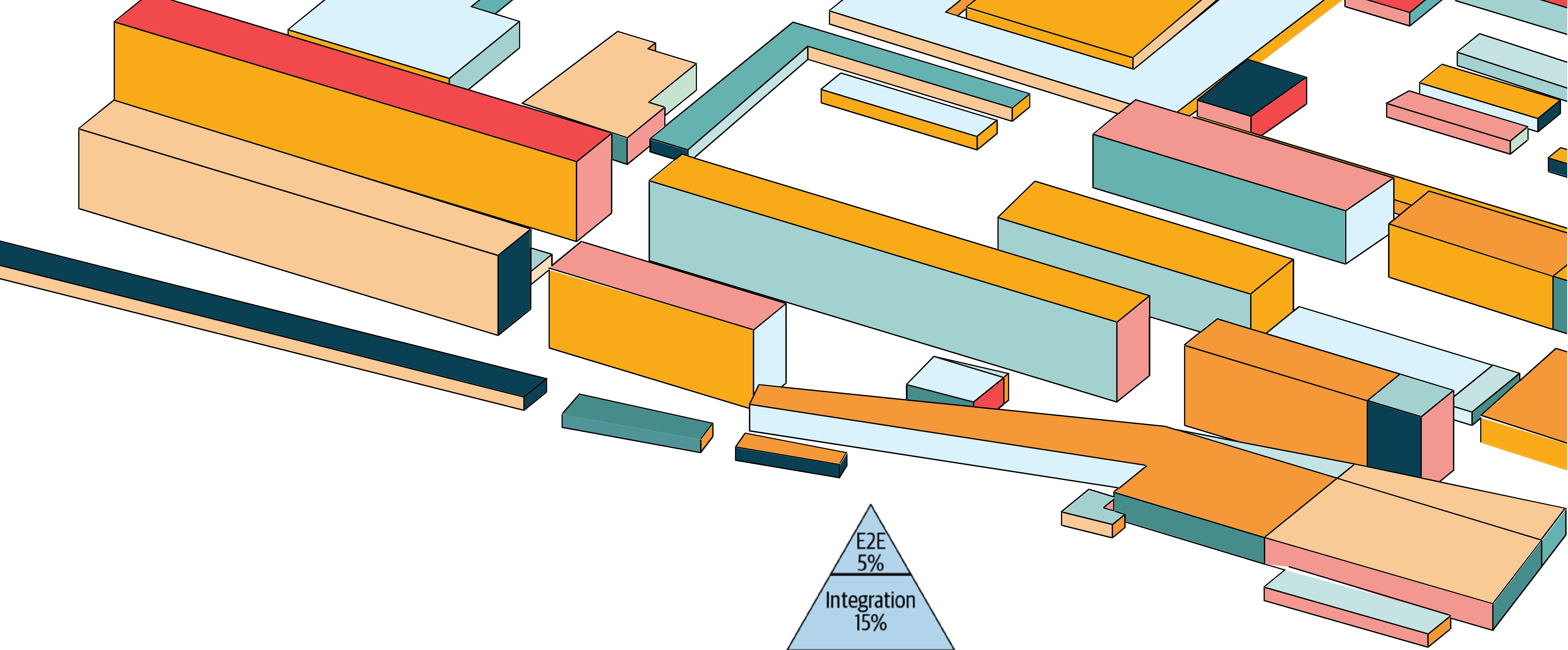
The method to be tested

```
@Test
public void displayTransactionResults_showsItemName() {
  transactionProcessor.displayTransactionResults(
      new User(), new Transaction(“Some Item”));
  assertThat(ui.getText()).contains(“You bought a Some Item”);
}
```

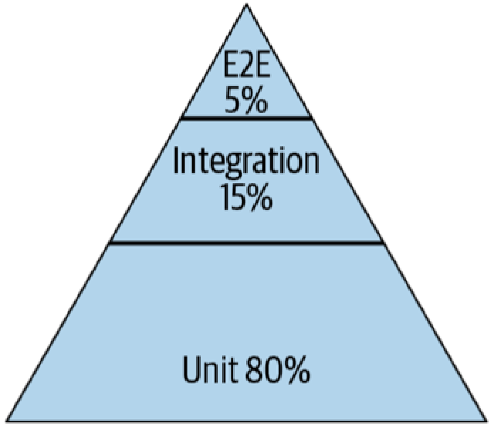
√

```
@Test
public void displayTransactionResults_showsLowBalanceWarning() {
  transactionProcessor.displayTransactionResults(
      newUserWithBalance(
          LOW_BALANCE_THRESHOLD.plus(dollars(2))),
      new Transaction(“Some Item”, dollars(3)));
  assertThat(ui.getText()).contains(“your balance is low”);
}
```

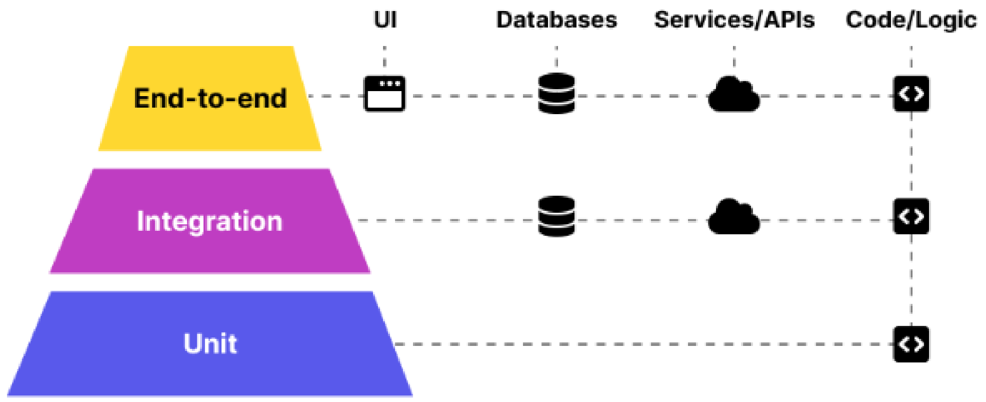
A behavior-driven test: rather than writing a test for each method, write a test for each behavior.



TEST DOUBLES



WHY TEST DOUBLES?



- Imagine writing a test suite for a function that sends a request to an external server and then stores the response in a database.
- The test suite may
  - take hours to run
  - become flaky (不稳定) due to issues like random network failures or tests overwriting one another’s data.
- Test doubles come in handy in such cases

WHAT ARE TEST DOUBLES?

A test double is an object or function that can stand in for a real implementation in a test, similar to how a stunt double can stand in for an actor in a movie.

TEST DOUBLES

- “Test doubles" are objects or code components that mimic the behavior of real objects or components in the system under test (SUT).
- Test doubles are commonly used to isolate the SUT and its dependencies, such as external services or libraries, by replacing them with lightweight, controllable substitutes.

- Fakes
- Stubs
- Mocks

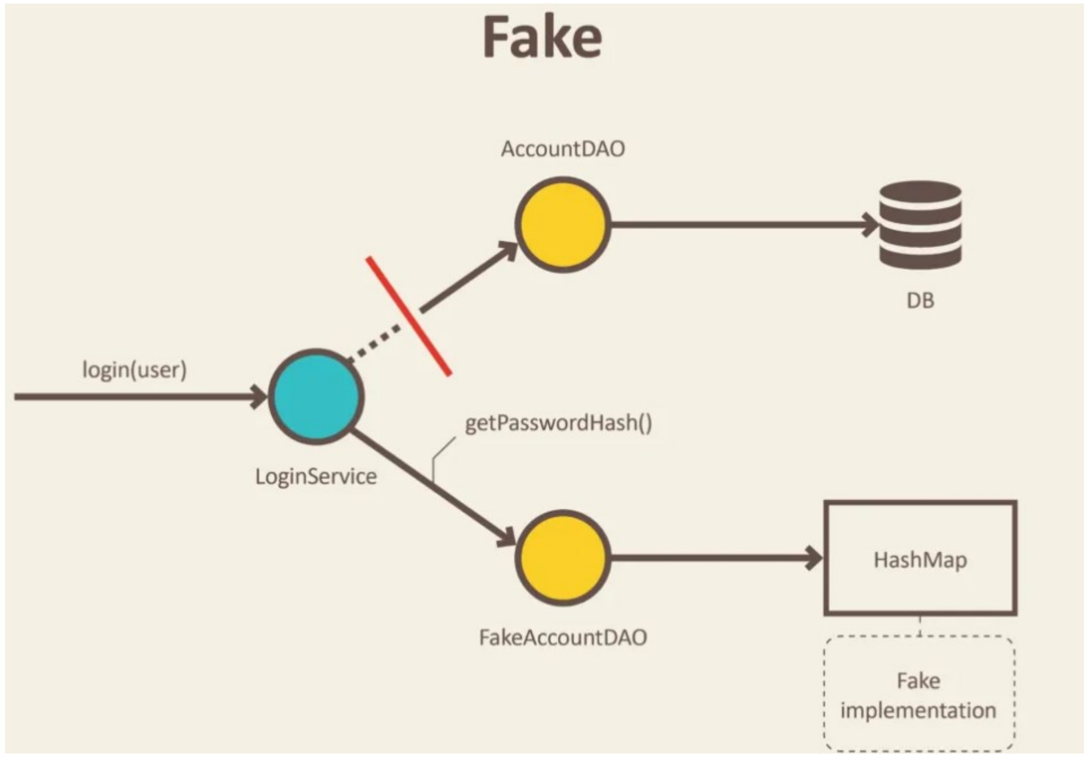
FAKES

- A fake is an implementation that behaves “naturally”, but is not “real”
- Fakes have a pre-written implementation of the object that they are supposed to represent
- Purpose: simplify the implementation of tests by removing unnecessary or heavy dependencies, usually used for performance reasons

Fakes are objects that have working implementations, but not same as production one. Usually they take some shortcut and have simplified version of production code.

FAKES - EXAMPLES

- In-memory database: designed to enable minimal response times by eliminating the need to access disks.
- You would never use this for production (since the data is not persisted), but it's perfectly adequate as a database to use in a testing environment.

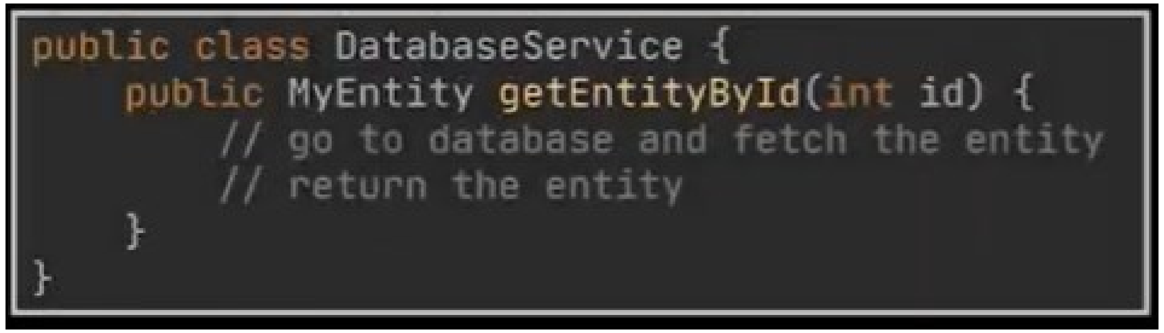


https://blog.pragmatists.com/test-doubles-fakes-mocks-and-stubs-1a7491dfa3da

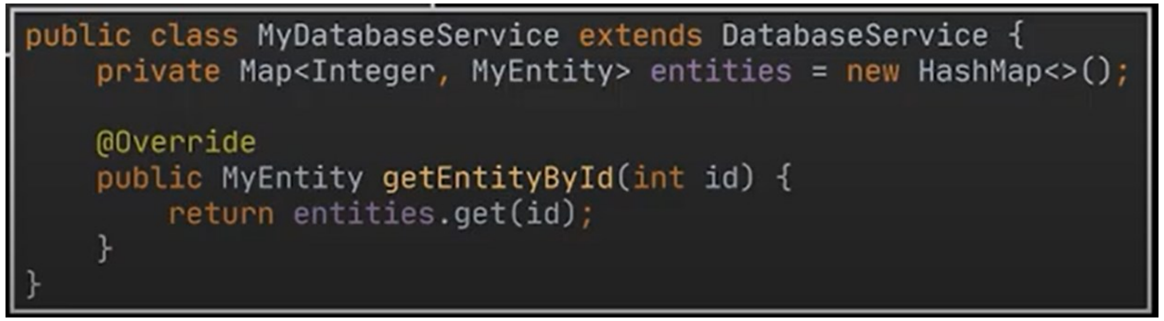
FAKES - EXAMPLES

- In-memory database: designed to enable minimal response times by eliminating the need to access disks.

- You would never use this for production (since the data is not persisted), but it's perfectly adequate as a database to use in a testing environment.



```java
public class DatabaseService {
    public MyEntity getEntityById(int id) {
        // go to database and fetch the entity
        // return the entity
    }
}
```



```java
public class MyDatabaseService extends DatabaseService {
    private Map<Integer, MyEntity> entities = new HashMap<>();

    @Override
    public MyEntity getEntityById(int id) {
        return entities.get(id);
    }
}
```

https://www.youtube.com/watch?v=oFBkzrwwwW8

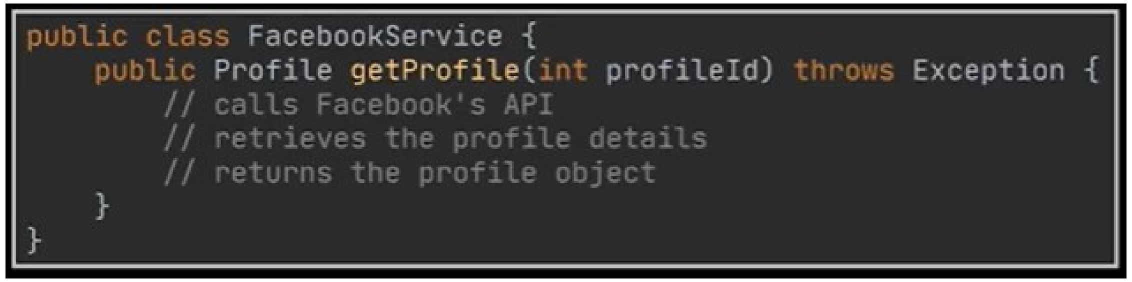
STUBS

- A stub is an implementation that behaves "unnaturally".
- It is preconfigured (usually by the test set-up) to respond to **specific inputs** with **specific outputs**.
- The purpose of a stub is to get your SUT **into a specific state**.

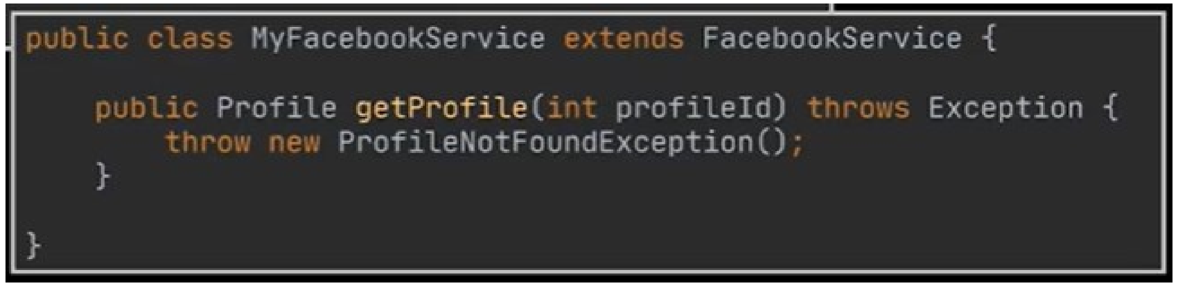
Stub is an object that holds predefined data and uses it to answer calls during tests. It is used when we cannot or don’t want to involve objects that would answer with real data or have undesirable side effects.

STUBS - EXAMPLES

- Test whether SUT notifies users when a request to XXX REST API returns 404 error
  - You could stub out the REST API with an API that **always returns 404**
- Test whether SUT notifies users when user profiles are not found
  - You could stub out the API that **always throws `ProfileNotFoundException`**



```
public class FacebookService {
    public Profile getProfile(int profileId) throws Exception {
        // calls Facebook's API
        // retrieves the profile details
        // returns the profile object
    }
}
```



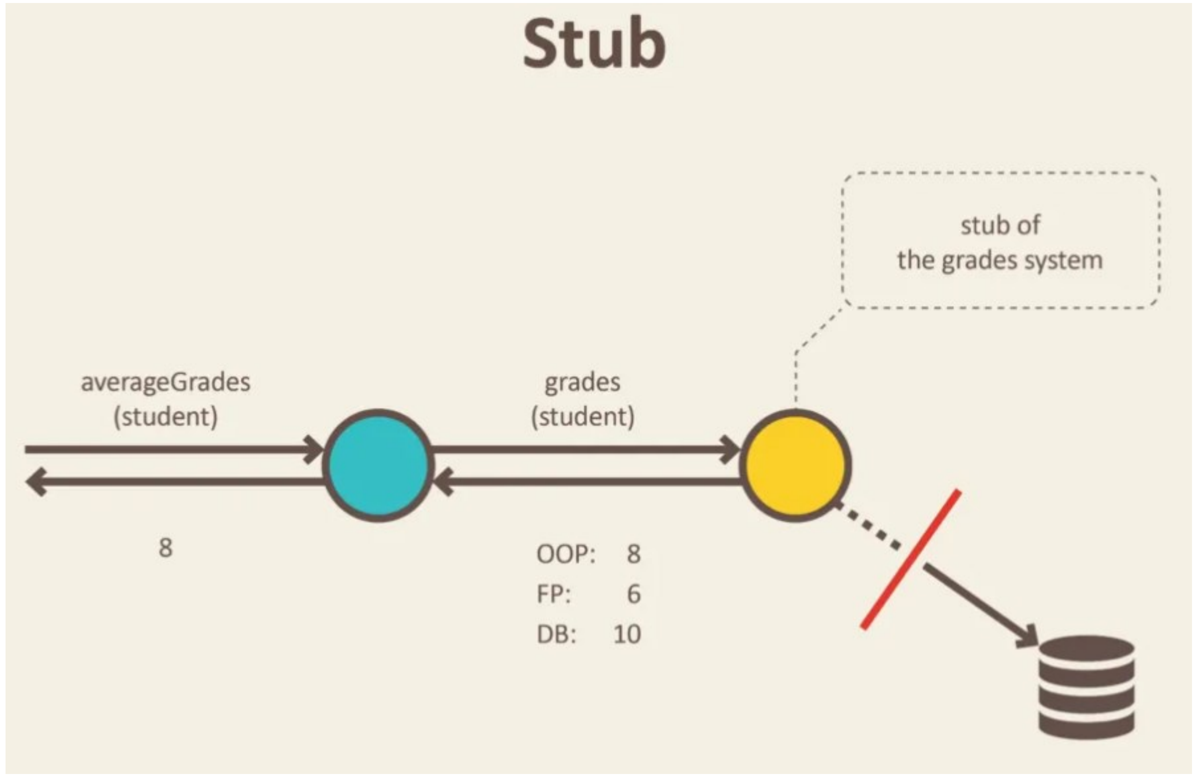
```
public class MyFacebookService extends FacebookService {

    public Profile getProfile(int profileId) throws Exception {
        throw new ProfileNotFoundException();
    }

}
```

https://www.youtube.com/watch?v=oFBkzrwwwW8

STUBS - EXAMPLES

- An object needs to grab some data from the database to respond to a method call.
- Instead of the real object from the database, we introduced a stub and defined what data should be returned.

https://blog.pragmatists.com/test-doubles-fakes-mocks-and-stubs-1a7491dfa3da



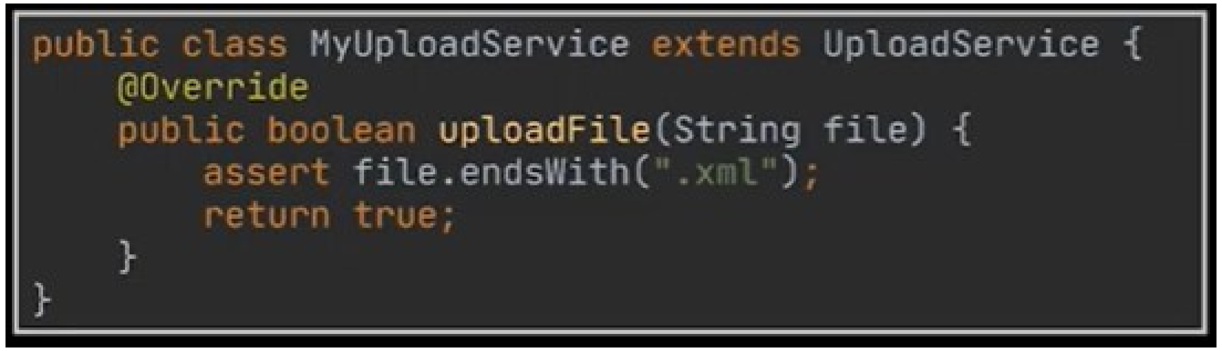
MOCKS

- A mock is similar to a stub, but with **verification** added in.
- Purpose: make assertions about how your SUT interacted with the dependency (whether a function in SUT is called in the correct way).
- We use mocks when we don't want to invoke production code or when there is no easy way to verify that intended code was executed.

- Example: a functionality that calls e-mail sending service.
  - We don't want to send e-mails each time we run a test. It's also not easy to verify in tests that a right email was send.
  - Only thing we can do is to verify that e-mail sending service was called.

MOCKS - EXAMPLES

- If you are writing a test for a system that uploads files to a website
- You could build a mock that accepts a file and **assert** that the uploaded file was correct.
- The mock doesn't actually upload the file (which is hard to verify)



```
public class MyUploadService extends UploadService {
    @Override
    public boolean uploadFile(String file) {
        assert file.endsWith(".xml");
        return true;
    }
}
```

https://stackoverflow.com/a/55030455/636398

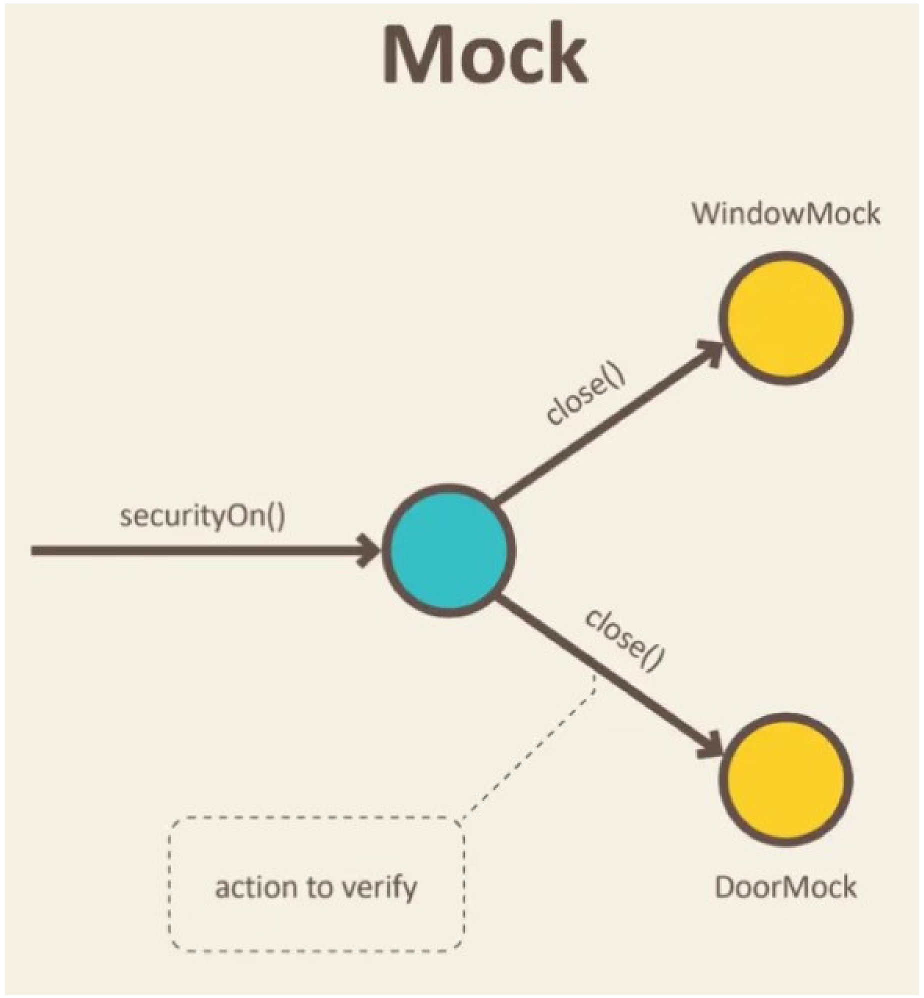
MOCKS - EXAMPLES

Example: a SecurityCentral software

- We don’t want to close real doors and windows to test
- Instead, we place door and window mocks objects in the test code.

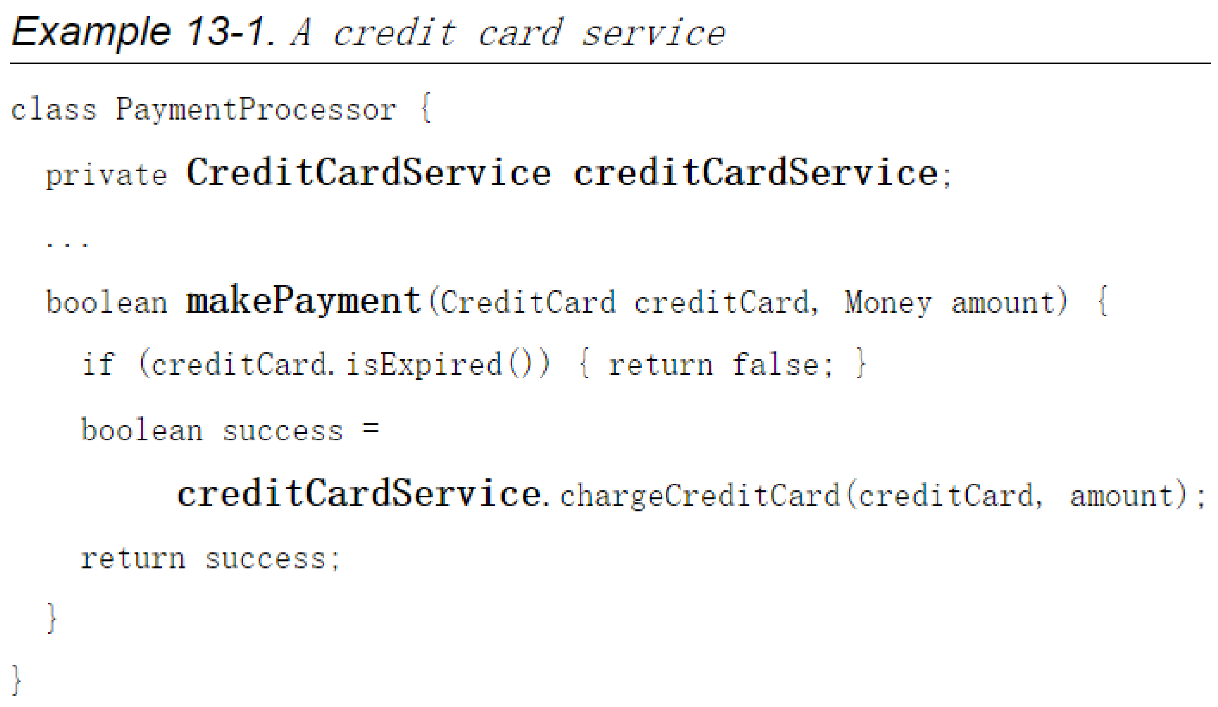
Whether doors and windows will be closed for real are the responsibility of Doors and Windows, which should be tested in independent unit tests.

https://blog.pragmatists.com/test-doubles-fakes-mocks-and-stubs-1a7491dfa3da



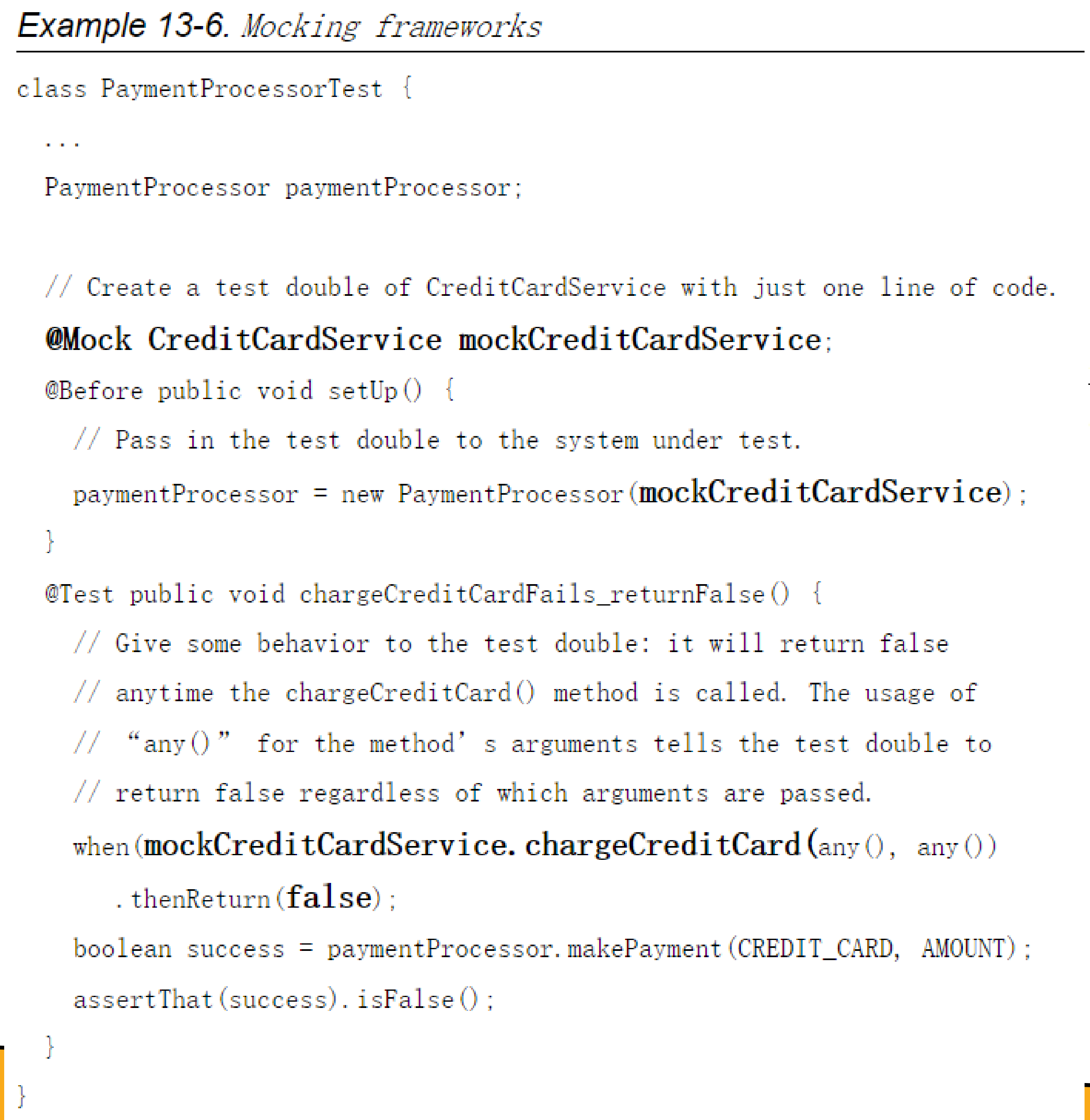
MOCKING FRAMEWORKS

A mocking framework is a software library that makes it easier to create test doubles within tests; it allows you to replace an object with a *mock*, which is a test double whose behavior is specified inline in a test



Example 13-1. A credit card service

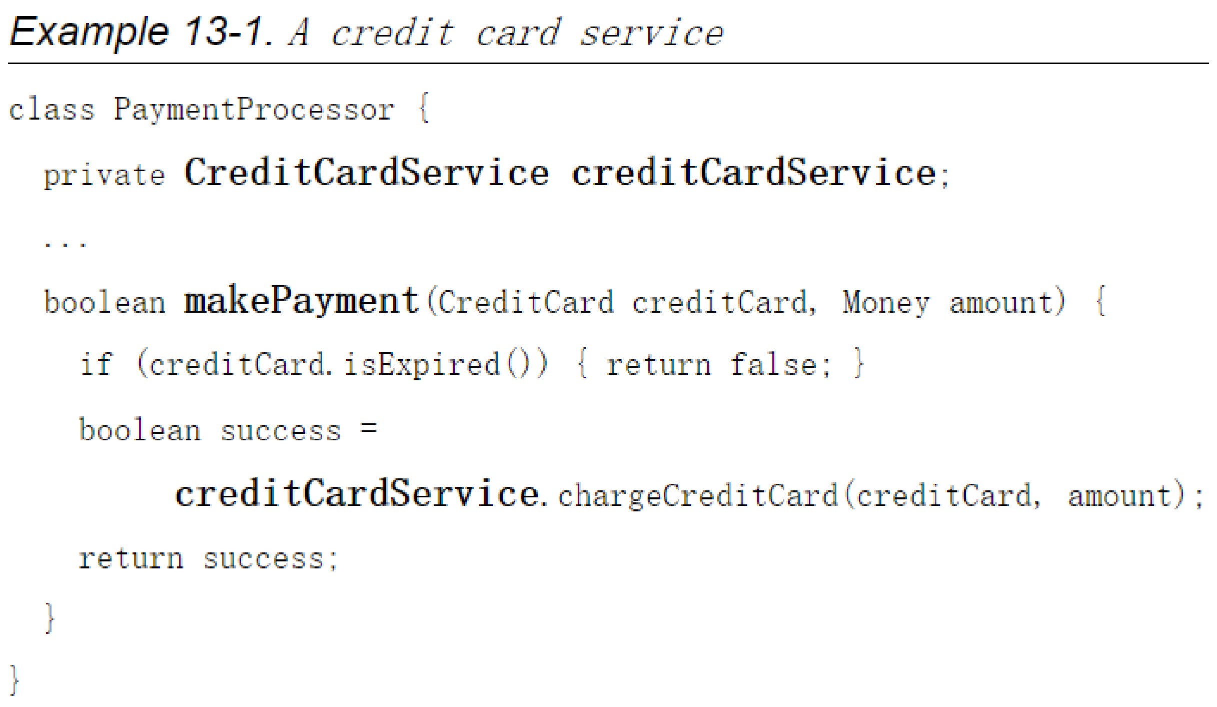
```
class PaymentProcessor {
  private CreditCardService creditCardService;
  ...
  boolean makePayment(CreditCard creditCard, Money amount) {
    if (creditCard.isExpired()) { return false; }
    boolean success =
        creditCardService.chargeCreditCard(creditCard, amount);
    return success;
  }
}
```



Example 13-6. Mocking frameworks

```
class PaymentProcessorTest {
  ...
  PaymentProcessor paymentProcessor;

  // Create a test double of CreditCardService with just one line of code.
  @Mock CreditCardService mockCreditCardService;
  @Before public void setUp() {
    // Pass in the test double to the system under test.
    paymentProcessor = new PaymentProcessor(mockCreditCardService);
  }
  @Test public void chargeCreditCardFails_returnFalse() {
    // Give some behavior to the test double: it will return false
    // anytime the chargeCreditCard() method is called. The usage of
    // “any()” for the method’ s arguments tells the test double to
    // return false regardless of which arguments are passed.
    when(mockCreditCardService.chargeCreditCard(any(), any())
       .thenReturn(false);
    boolean success = paymentProcessor.makePayment(CREDIT_CARD, AMOUNT);
    assertThat(success).isFalse();
  }
}
```

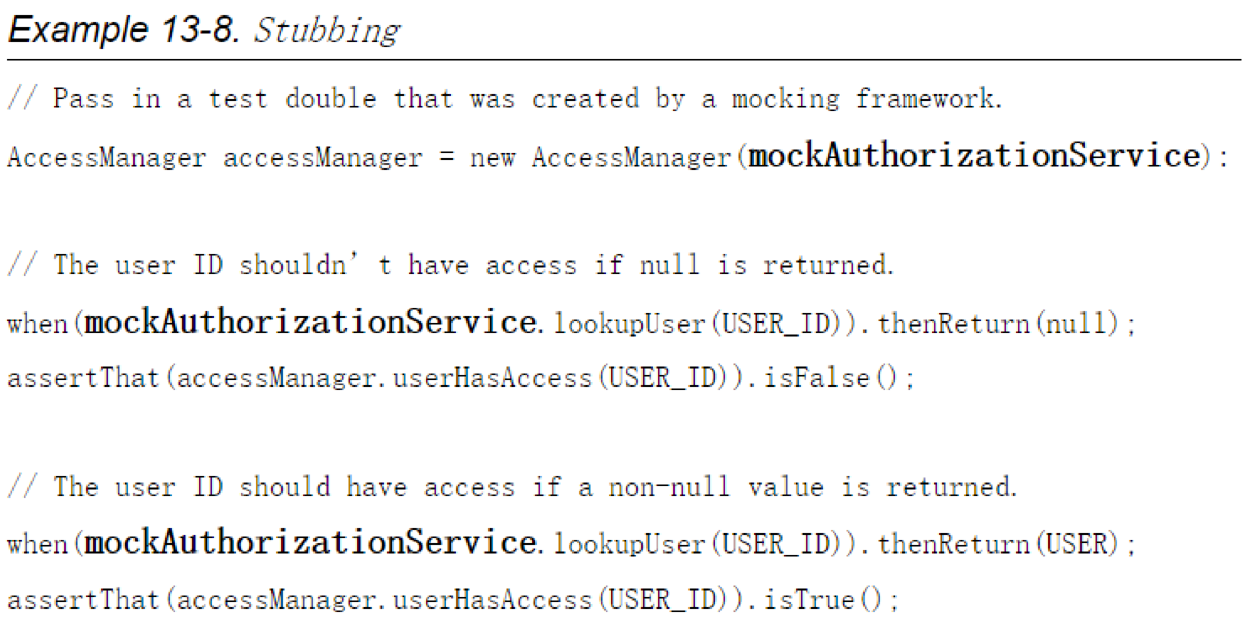
Mockito, a mocking framework for Java.



Example 13-1. A credit card service

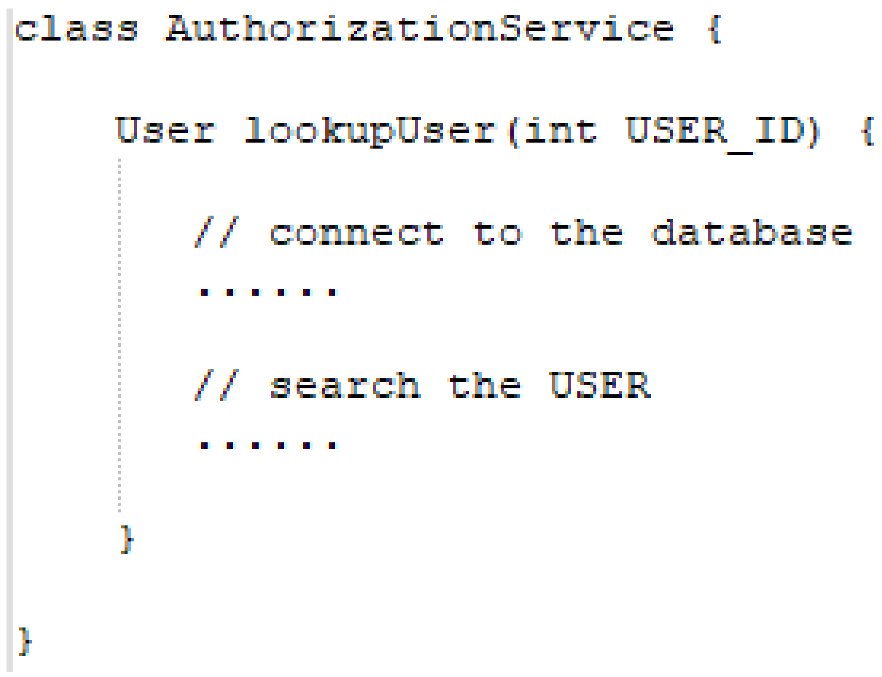
```
class PaymentProcessor {
  private CreditCardService creditCardService;
  ...
  boolean makePayment(CreditCard creditCard, Money amount) {
    if (creditCard.isExpired()) { return false; }
    boolean success =
        creditCardService.chargeCreditCard(creditCard, amount);
    return success;
  }
}
```

MOCKING FRAMEWORKS



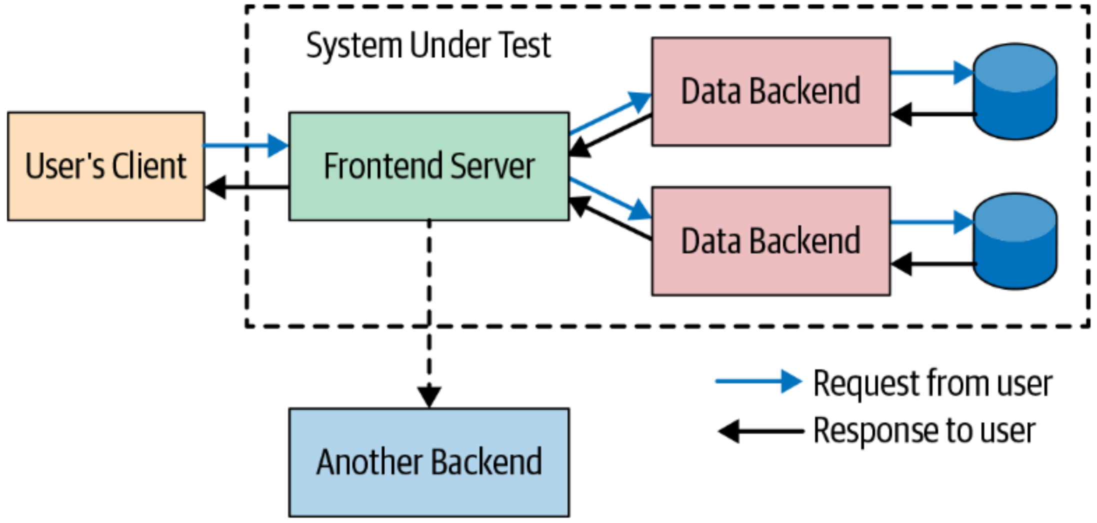
Example 13-8. Stubbing

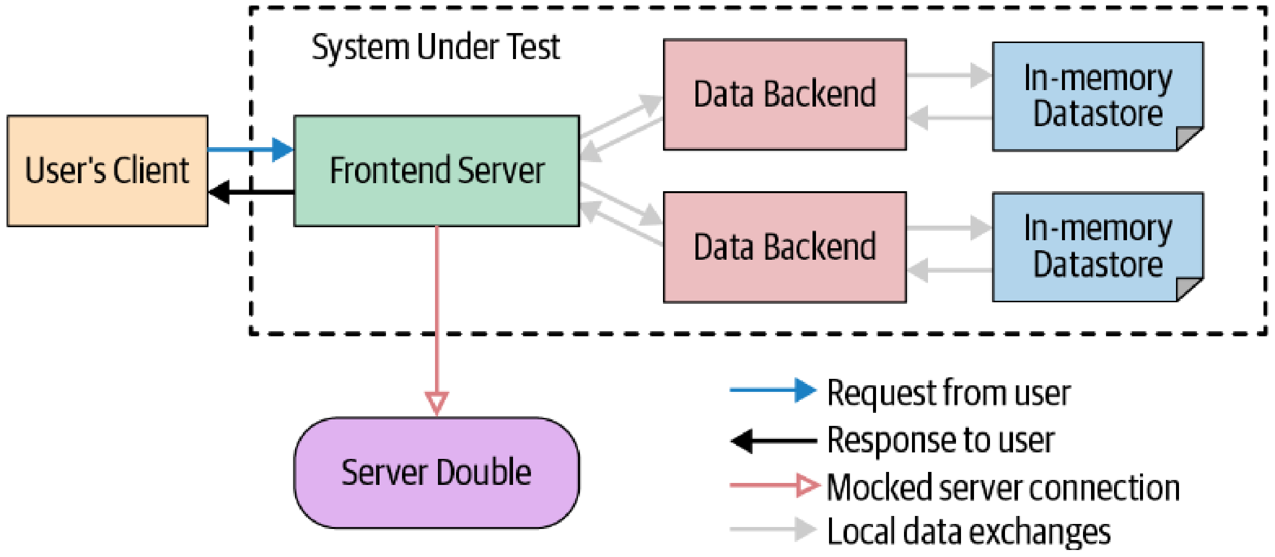
```
// Pass in a test double that was created by a mocking framework.
AccessManager accessManager = new AccessManager(mockAuthorizationService);

// The user ID shouldn’t have access if null is returned.
when(mockAuthorizationService.lookupUser(USER_ID)).thenReturn(null);
assertThat(accessManager.userHasAccess(USER_ID)).isFalse();

// The user ID should have access if a non-null value is returned.
when(mockAuthorizationService.lookupUser(USER_ID)).thenReturn(USER);
assertThat(accessManager.userHasAccess(USER_ID)).isTrue();
```



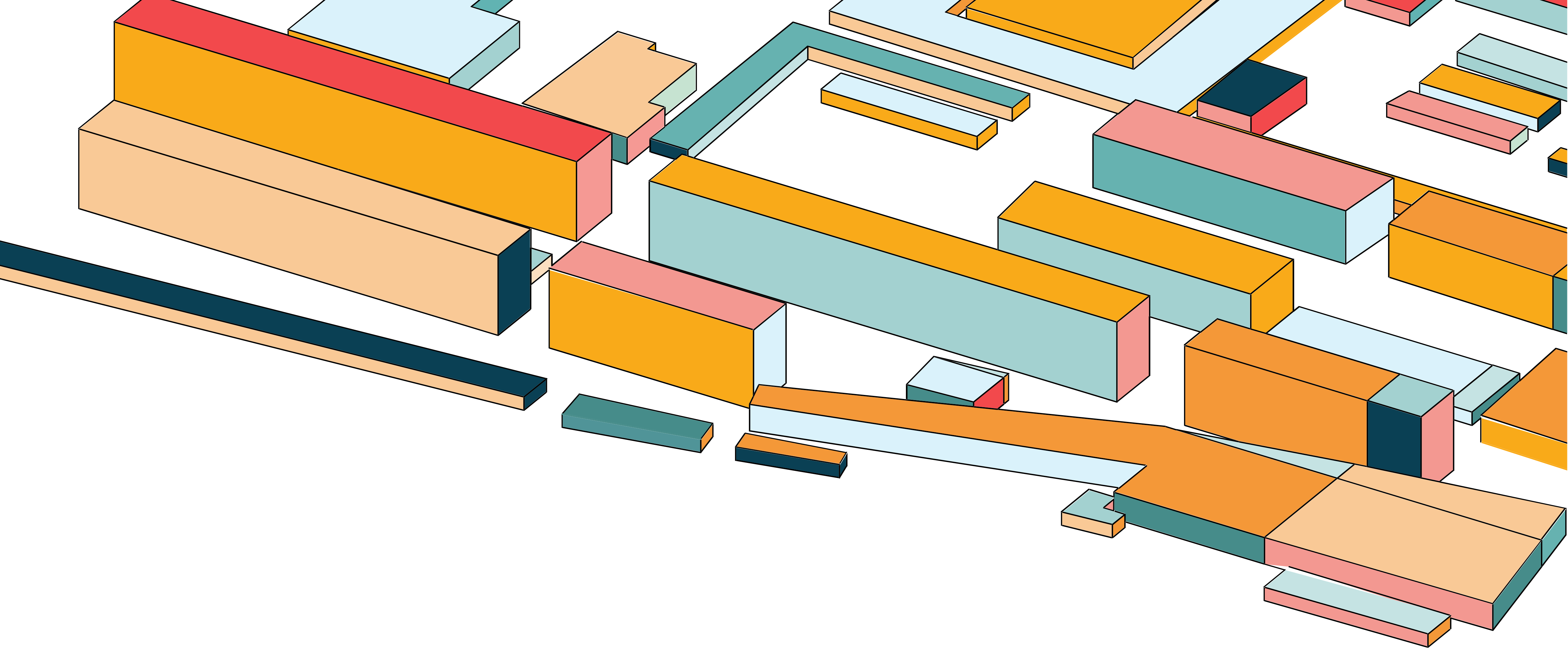
```
class AuthorizationService {

    User lookupUser(int USER_ID) {

        // connect to the database
        ......

        // search the USER
        ......

    }

}
```

TEST DOUBLES SUMMARY





https://abseil.io/resources/swe-book/html/ch14.html



UI TESTING

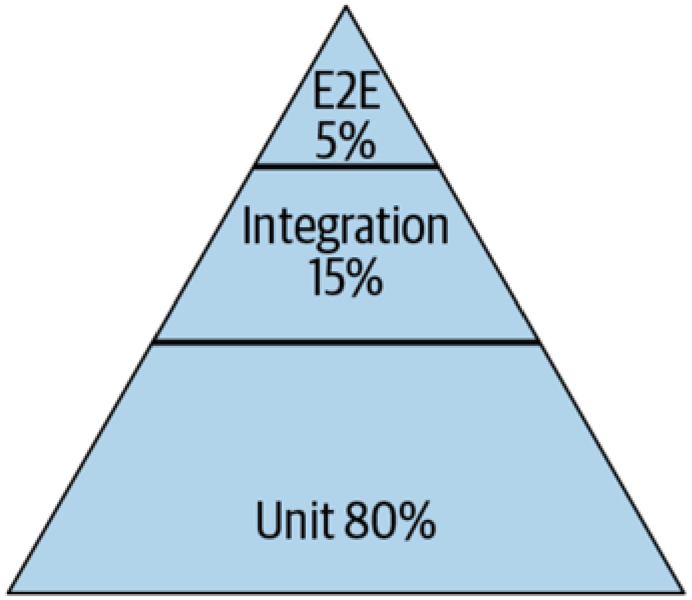
UI TESTING OVERVIEW

- UI is the visual part of a software that determines how users interact with the software and how information is displayed on the screen
- UI testing checks the application via the user interface, in the same way an end user would

UI TESTING OVERVIEW

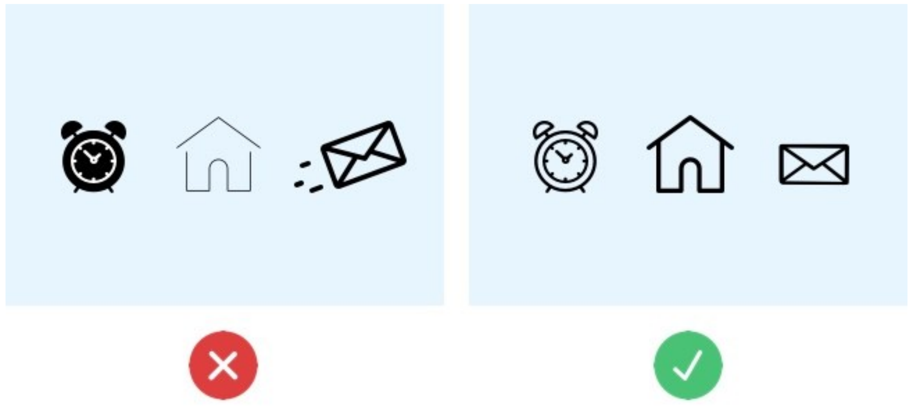
- UI tests are very powerful because they go “end-to-end” from the UI layer down, which test all different parts of an application from beginning (UI) to end (the underlying service, database, etc.)

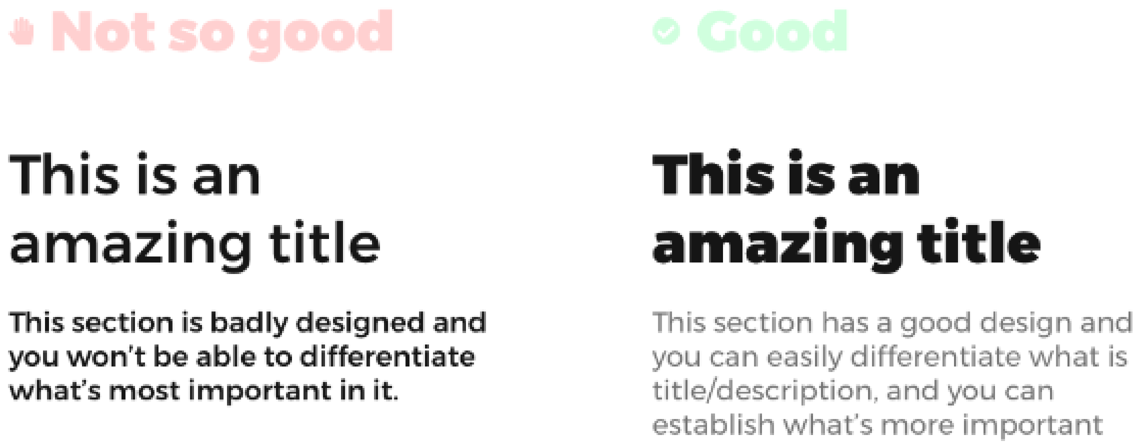
- UI testing can
    - Determine whether an application satisfies requirements
    - Demonstrate that it is fit for purpose
    - Detect defects



WHAT TO LOOK FOR IN UI TESTING?

- **Consistency**: consistency of colors, font types, and other visual elements.
- **Spelling**: spelling errors throughout the application
- **Typography**: Is the text easily readable? Does it have enough contrast with the background?





This is an amazing title

This section is badly designed and you won't be able to differentiate what's most important in it.

This is an amazing title

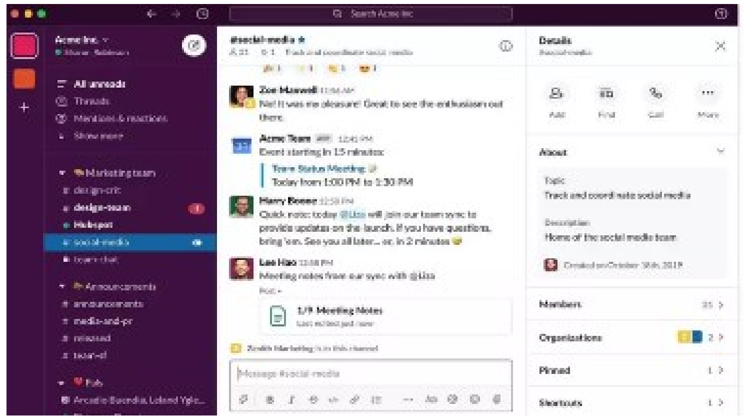
This section has a good design and you can easily differentiate what is title/description, and you can establish what's more important

Mostly manual

WHAT TO LOOK FOR IN UI TESTING?

- **Behavior of interactive elements**: Do the buttons, clicks, hovers, drag-and-drops, etc. work as intended?
- **Functional validation**: Do inputs produce the expected outputs?
- **Adaptability**: Ensure that UI elements adapt and are displayed correctly in different devices, browsers, screen formats and sizes, and OS.

Can be automated



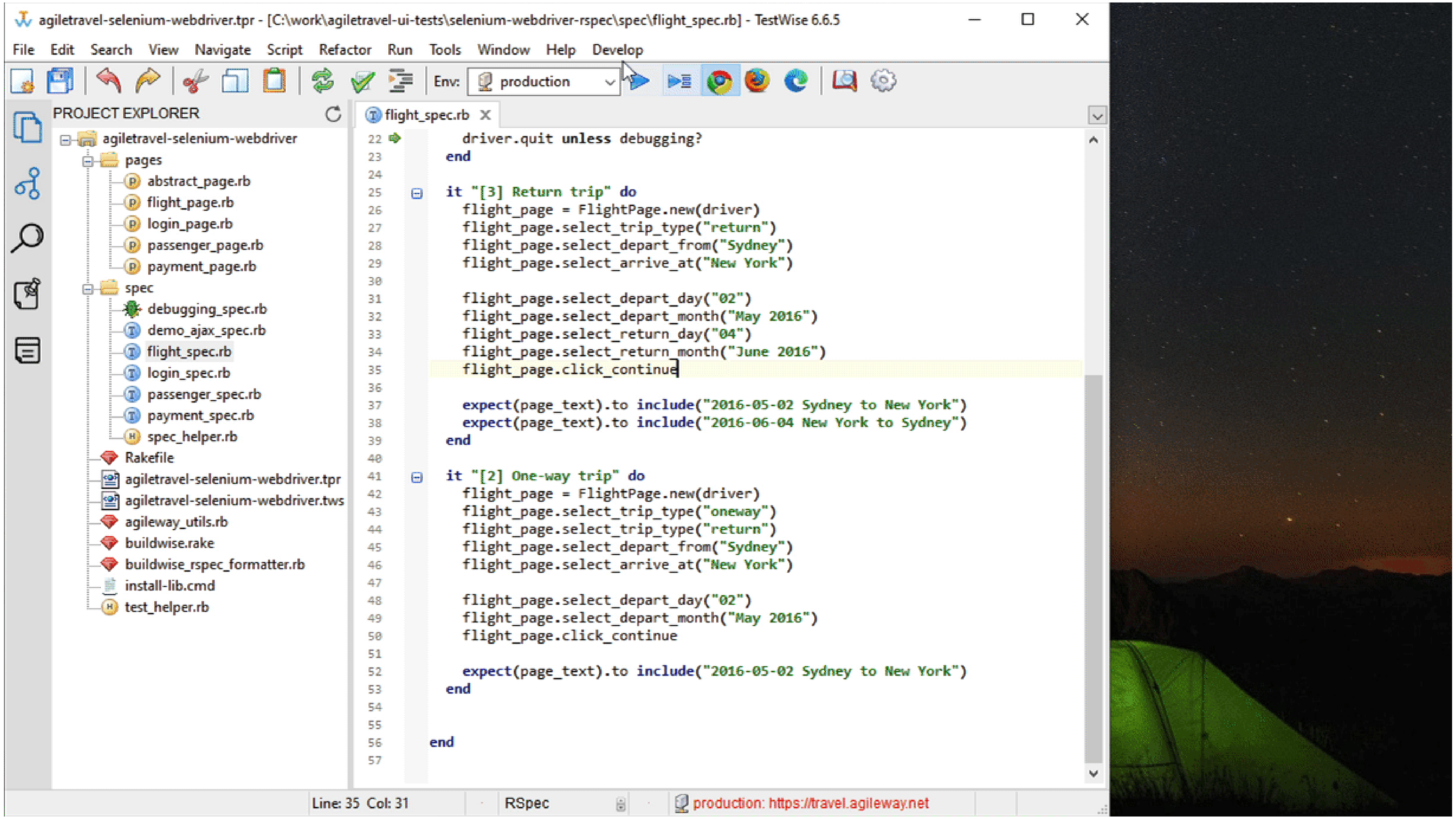
UI TESTING TOOLS

Example of UI functional validation:

- If you, "add an item to cart" you need to validate that the correct item, price, and quantity are properly added to the cart.
- Is there validation in place to prevent users from entering unreasonable data such as negative numbers or special characters that aren't allowed?
- Can you verify that character length restrictions or required formats (e.g. phone number) aren't violated?

UI testing tools (e.g., Selenium) allow developers to create programs that act like robots, interacting with websites to check for any issues or bugs automatically.

Selenium


agiletravel-selenium-webdriver.tpr - [C:\work\agiletravel-ui-tests\selenium-webdriver-rspec\spec\flight_spec.rb] - TestWise 6.6.5
File Edit Search View Navigate Script Refactor Run Tools Window Help Develop
Env: production
PROJECT EXPLORER
agiletravel-selenium-webdriver
pages
abstract_page.rb
flight_page.rb
login_page.rb
passenger_page.rb
payment_page.rb
spec
debugging_spec.rb
demo_ajax_spec.rb
flight_spec.rb
login_spec.rb
passenger_spec.rb
payment_spec.rb
spec_helper.rb
Rakefile
agiletravel-selenium-webdriver.tpr
agiletravel-selenium-webdriver.tws
agileway_utils.rb
buildwise.rake
buildwise_rspec_formatter.rb
install-lib.cmd
test_helper.rb
flight_spec.rb
Line: 35 Col: 31
RSpec
production: https://travel.agileway.net

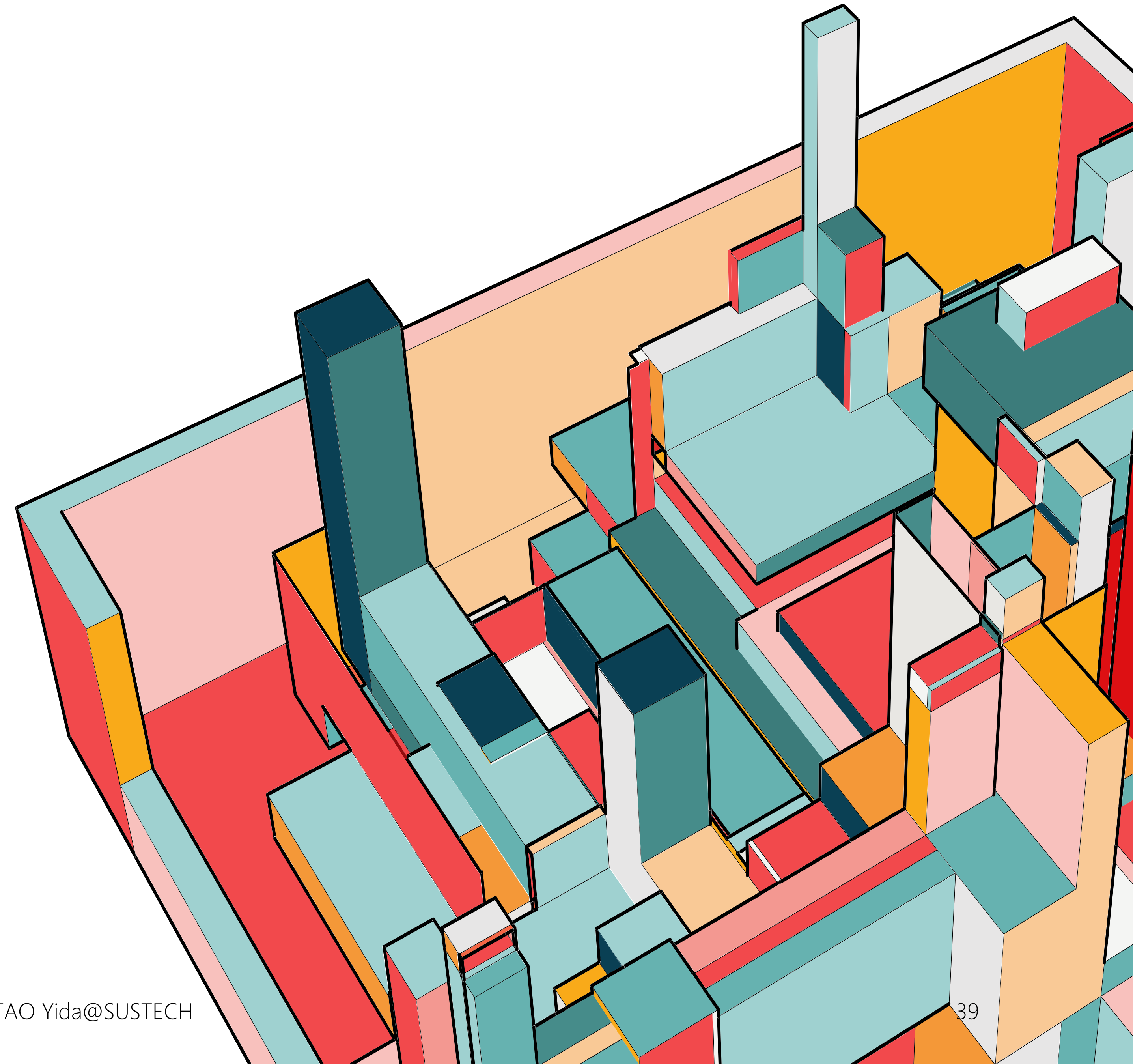
```ruby
    driver.quit unless debugging?
  end

  it "[3] Return trip" do
    flight_page = FlightPage.new(driver)
    flight_page.select_trip_type("return")
    flight_page.select_depart_from("Sydney")
    flight_page.select_arrive_at("New York")

    flight_page.select_depart_day("02")
    flight_page.select_depart_month("May 2016")
    flight_page.select_return_day("04")
    flight_page.select_return_month("June 2016")
    flight_page.click_continue

    expect(page_text).to include("2016-05-02 Sydney to New York")
    expect(page_text).to include("2016-06-04 New York to Sydney")
  end

  it "[2] One-way trip" do
    flight_page = FlightPage.new(driver)
    flight_page.select_trip_type("oneway")
    flight_page.select_trip_type("return")
    flight_page.select_depart_from("Sydney")
    flight_page.select_arrive_at("New York")

    flight_page.select_depart_day("02")
    flight_page.select_depart_month("May 2016")
    flight_page.click_continue

    expect(page_text).to include("2016-05-02 Sydney to New York")
  end


end
```

https://medium.com/geekculture/headless-browser-testing-clarified-d544ef0acf43

READINGS

- Chapter 11-13. Software Engineering at Google by Winters et al

- 第9章 软件测试. 现代软件工程基础 by 彭鑫 et al.



NEXT

- Software Documentation