

CITS5501 Software Testing and Quality Assurance

Test Automation

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Re-cap

- ▶ We looked at testing concepts – failures, faults/defects, invariants, and erroneous/inconsistent runtime states
- ▶ We looked at specifications and APIs – these help us answer the question, “How do we know what to test against?”
i.e., What is the correct behaviour for some piece of software?
- ▶ We have discussed what *unit tests* are, and what they look like

Questions

- ▶ What's the structure of a test?
- ▶ How do different types of test relate?
- ▶ How do we come up with tests?
- ▶ How do we know when we have enough tests?
- ▶ What are typical patterns and techniques when writing tests?
- ▶ How do we deal with difficult-to-test software?
(e.g. software components with many *dependencies*)
- ▶ What sorts of things can be tested?

Questions

▶ What's the structure of a test?

Any test can be seen, roughly, as asking: “When set up appropriately – if the system (or some part of it) is asked to do X , does its actual behaviour match the expected behaviour?”

Test structure

Drilling down a little more into what this means, a test case needs to do the following three things:

1. Prepare the system (and/or an appropriate environment) so that it's in a suitable state for us to invoke some behaviour.
2. Invoke the desired behaviour.
3. Work out whether the system did what we expected it to.

Sometimes each of these will be very simple; sometimes they're very complex.

Test structure

If your test is going to be implemented as code, it's often helpful do each of the three things we mentioned in exactly the order given. If you do so, then you're following the **Arrange-Act-Assert** pattern for writing tests.

Arrange Set up an appropriate environment

Act Invoke the desired behaviour

Assert Work out what the observed behaviour was, and check whether it's the same as the expected behaviour.

Test patterns – example 1

Let's consider the JUnit test we saw in the previous lecture:

CalculatorTest

```
1 public class CalculatorTest {
2     @Test
3     public void evaluatesExpression() {
4         Calculator calculator = new Calculator();
5         int sum = calculator.evaluate("1+2+3");
6         assertEquals(6, sum);
7     }
8 }
```

Test structure – example 1

CalculatorTest

```
1 public class CalculatorTest {  
2     @Test  
3     public void evaluatesExpression() {  
4         Calculator calculator = new Calculator();  
5         int sum = calculator.evaluate("1+2+3");  
6         assertEquals(6, sum);  
7     }  
8 }
```

- ▶ We **arrange** in line 4 – we invoke the constructor (“`new Calculator()`”) so we’ve got an object to operate on.
- ▶ We **act** in line 5 – we invoke the `evaluate()` method of the object we constructed, and pass that method the string “1+2+3”.
- ▶ We **assert** in line 6 – we check that result we got (`sum`) equals the result we expected (6).

More complex “assertions”

In the code examples we’ve seen, it’s very simple to check whether the observed behaviour matches the expected behaviour.

All we expected the method under test to do was return a value – and it’s very simple to check whether that value is what we expected.

But what if the specification for the `evaluate()` method said that the result shouldn’t be returned, but rather written to a file called “`myresult.txt`”?

How can we tell if the test passed or failed?

We’d need to run extra methods to open that file, read its contents, and check that the contents was what we expected. All this would be part of the “assertion” stage.

Ammann and Offutt textbook terminology

The Ammann and Offutt textbook divides the structure of tests up a bit differently.

For reference, it considers a test to consist of:

- ▶ Test values: anything required to set up a system or component, “ask it do” something, observe the result, and clean up the system so as to put it back in a stable state.
- ▶ Expected values: what the system is expected to do.

“Values” is being used in a very broad sense. Suppose we are designing system tests for a phone – then the “test values” might include, in some cases, physical actions to be done by a tester to put the phone in a particular state (e.g. powered on and with the “Contacts” list displayed).

Ammann and Offutt textbook terminology

The textbook goes into quite a bit of detail about particular sorts of test values.

For instance:

- ▶ “prefix values” (which largely correspond to things we do in the “Arrange” part of a test to set up test fixtures)
- ▶ “verification values” (things we need to do in order to observe or measure the behaviour of a system or component – running a database query, perhaps)
- ▶ “exit values” (things we need to do in order to reset or “tear down” our fixtures, and put the system back into a stable state again).

For the most part, we will not need to make use of this terminology.

Cleaning up/“teardown” methods

Ammann and Offutt’s “exit values” don’t really correspond to anything in the “Arrange–Act–Assert” pattern.

If we need to do any sort of “cleanup” after a test, we would just do it after the “Assert” stage.

If we have multiple tests that all require the *same* cleanup steps (deleting files or resetting a database to a known state), it would be poor programming style to copy and paste the same cleanup code again and again. (Why?)

Instead, most test frameworks give us a way of specifying bits of code – often called “teardown methods” – that should be run after each test in some test suite.

We’ll see examples of these later.

Test structure – example 2

Tests need not always be implemented as code.

For instance, we might want to test whether a whole travel booking system is “easily usable” (perhaps as part of an acceptance test).

Let's suppose the relevant system requirement is:

“Travel agents shall be able to use all the system functions after successful completion of a training course designed by the software provider. After this training, the average number of errors made by experienced users shall not exceed two per hour of system use.”

When we document our test, our “input values” might be everything we need to do to get trial versions of the system set up on the customer's premises, and have the system up and available for trial use by a selection of travel agents.

Test structure – example 2

In how much detail do we document these “input values”? It depends on the situation. If a lot is at stake, we might document all the actions/inputs, and what preparation is needed, and what things the customer needs to be provide, in great detail. For a small system, if less is at stake, less detail as needed.

(We give sufficient detail to reduce the *risk* of things going wrong to an acceptable level – more on this in the lecture on risk.)

Test structure – example 2

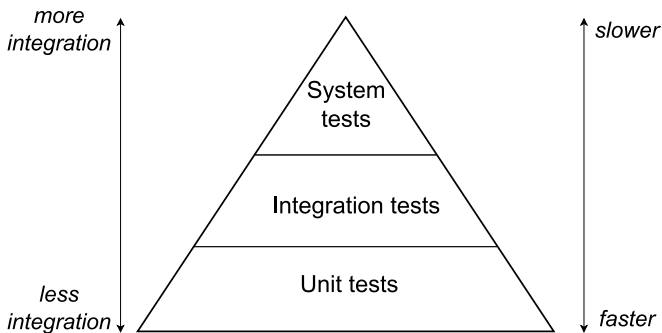
What are the “expected values” in this scenario?

It's the number of errors per user not exceeding two per hour of system use.

Questions

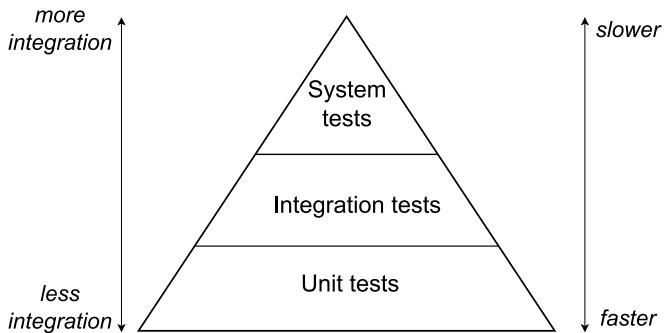
- ▶ How do different sorts of tests relate?

A common way of thinking about the way tests relate is to think of them as forming a “test pyramid”:¹



¹Adapted from Ham Vocke, [“The Practical Test Pyramid”](#), which is adapted from Mike Cohn (2009) *Succeeding with Agile*.

How tests relate



(Different authors might put other tests in the top level, instead or as well – for instance, UI tests and end-to-end tests.)

Or might add a higher level still, for client acceptance tests or manually run tests.)

How tests relate

- ▶ *Unit tests* are at the bottom of the hierarchy, and directly test small parts of the system created during *system implementation*.

They should have the properties we said all good unit tests should have (independent, quick to run), and should be run frequently as a project progresses. (e.g. for every change we make to a class)

How tests relate

- ▶ *Integration tests* are in the middle of the hierarchy. They test whether two or more components interoperate properly.

They focus on the flow of data and/or control between components, and often will test for properties implied by the system *design*.

They often are run less frequently than unit tests – e.g. if a unit is being changed, we might run integration tests once the unit tests are passing.

- ▶ Higher-level tests – system tests and subsystem tests of various sorts, perhaps including acceptance tests – usually take more effort to set up, and are run fewer times (perhaps just once, in the case of acceptance tests).

Questions

- ▶ How do we come up with tests?
- ▶ How do we know when we have enough tests?

Both of these are covered in the next few lectures. We look at ways of grouping together different sorts of input so that we don't need to test exhaustively, and at ways of working out how much of the system we have tested (and ought to test).

Coming up with tests

In brief, we come up with tests by looking at *requirements and specifications*, and thinking about the system – modelling it – in different ways.

Coming up with tests

Consider an Internet-connected toaster.

At a high level, the *system* level, we can look at the system in a few different ways, depending on what part of the system requirements and specification we're trying to test.

Sometimes, it'll be useful to think of the system as a *function* – something that takes stuff *in* (parameters and state) and spits something *out* (a return value, and/or a new state).

e.g. We can think of a toaster as taking bread (or crumpets, or muffins, or other bread products) and control settings *in*, and spitting something *out* (toast).

Coming up with tests

But we also might have some kind of *use-case* for how the toaster should be used:

Scenario: User is in the toaster's physical location

1. User inserts a bread product.
 2. System detects product composition, and prompts user for a toastiness level.
 3. User enters toastiness level.
 4. If the user makes an error, an error message is displayed and step 2 is repeated.
 5. System toasts the bread product.
 6. When system detects the desired toastiness level has been achieved, heat is turned off and a klaxon is sounded.
-

Coming up with tests

Use cases can be thought of as *graphs* – steps, and links between steps – and this way of thinking can help us come up with tests (and decide if we've tested enough).

Other aspects of the system can be thought of as *logic expressions* and as *grammars* or *syntaxes*.

Pretty much any aspect of the system we're interested in can be thought of in one of these ways (as a function, a graph, a [set of] logic expressions, or a grammar).

More on this in later lectures.

Questions

- ▶ What are typical patterns and techniques when writing tests?

We look at data-driven tests (running “the same” test, but on different sets of input and expected output), and property-based tests (testing invariant properties of code or data).

Questions

- ▶ How do we deal with difficult-to-test software?
(e.g. software components with many *dependencies*)

We saw that unit tests should test things in isolation – what if something is hard to isolate?

(e.g. it uses a database)

We discuss the use of *mocks* to handle this.

Questions

- ▶ What sorts of things can be tested?

Not *just* the modules in your code!

We can also test examples and code fragments appearing in documents (e.g. user manuals), API documentation, and provided as example programs.

Coming up

- ▶ Testing is all about *running* software to see how it behaves.
- ▶ *Static* analysis of software consists of any way of inspecting or analysing software (or some other static artifact) *without* running it.
- ▶ We will look at:
 - ▶ Inspections (analysis by humans)
 - ▶ Static analysis and (late in the course) formal methods

Coming up

- ▶ Then we will consider software quality more broadly (looking at processes and standards).

How to use assertion methods – some tips

- ▶ In JUnit, the parameter order for assertions is: expected value, then actual value, then message. (Hover over the assertion method in your IDE to see the JavaDoc tooltip.)
- ▶ It's good practice to give a message, and will be worth marks in assessments.
- ▶ In JUnit, the assertions are *overloaded* so as to apply to any of the primitive types, any of the array types, and anything inheriting from `Object` (i.e., any reference type)
- ▶ Reference types need a sensible `.equals()` method in order for equality tests to work. Most classes will already have an `.equals()` method, but if you write your own classes, you'll need to implement one.
- ▶ When comparing aggregate types like arrays or containers – don't loop over them and compare individual elements, just compare the aggregate types directly.

Reasons for Test Doubles

- ▶ Component has not been written
- ▶ The real component does something destructive that we want to avoid during testing (unrecoverable actions)
- ▶ The real component interacts with an unreliable resource
- ▶ The real component runs very slowly
- ▶ The real component creates a test cycle
 - ▶ A depends on B, B depends on C, C depends on A

A test double is a software component that implements partial functionality to be used during testing

Dependencies

- ▶ Very often, a class or function is not designed to work on its own, but in combination with other classes or functions -
e.g. an `AddressBook` class may make use of a `Contact` class
- ▶ or with other subsystems, or external systems:
 - ▶ dependency on a database for an HR system
 - ▶ dependency on a network, for an Internet chat system
 - ▶ dependency on particular hardware devices
- ▶ How do we deal with these?

Mocks, stubs and more

- ▶ Often, we'll use objects or function that mimic other ones for testing purposes. There does not seem to be any universally accepted term for these, but one author (Gerard Meszaros) uses the generic term "Test Double".
- ▶ Specific sorts of Test Double -
 - ▶ Dummy objects
 - ▶ Fake objects
 - ▶ Stubs
 - ▶ Spies
 - ▶ Mocks

[Fowler, in e.g. "Mocks Aren't Stubs", uses Meszaros's terminology.]

Dummy objects

- ▶ These are objects that are passed around but not used – for instance, they may be used to fill parameter lists (in statically typed languages).
 - ▶ In languages with a `null`, `Nil` or `undefined` value, we might be able to use that value
(which also serves to document the fact that we don't care what it is)

Fake objects

- ▶ *Fake* objects actually do have working implementations, but for some reason are not suitable for production
 - ▶ An example of this is when we use an in-memory database, instead of an on-disk database

Stubs

- ▶ Stubs (often, “stub methods”) provide canned answers to calls made during the test –
i.e., the answers are usually fixed, and don’t change in response to the parameters passed

Spies

- ▶ These are stubs that *record information* on how they were called.
- ▶ These are particularly useful for testing code that calls (e.g.) an object representing a server, such as a mail server, or which writes to a file-like object.

Spies – example

- ▶ In Java, we often write to files (or network sockets) using classes like `BufferedWriter`
- ▶ If we want to verify, in some unit test, what is written, we could use a “Spy” class that implements the `java.io.Writer` class – but instead of writing to a file, it records whatever data would have been written
- ▶ In Python, we do not have static types, and any class with a “`write()`” method suffices.
- ▶ Making our code agnostic about what sort of thing it is writing to has the benefit that if we *do* decide to change it at a later date, we don't have to revise our tests

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 - ▶ Suppose our code uses a database; we know that to work correctly, it must call the `connect()` method of a database object, and can then call the `query()` method; but it is an error to call `query()` before `connect()`.

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 - ▶ Suppose our code uses a database; we know that to work correctly, it must call the `connect()` method of a database object, and can then call the `query()` method; but it is an error to call `query()` before `connect()`.
 - ▶ Our mock object can contain code that checks whether `query()` has been called before `connect()`.

Mocks – another example

- ▶ We might have a order fulfilment system that is supposed to send an email when (for some reason) an order can't be fulfilled.
- ▶ The class that handles sending emails may need particular methods to be called, in a particular order; we can write a *mock* that tests that they are called in the right way.

Mocks in Python

- ▶ Python has the standard library `unittest.mock`
- ▶ `MagicMock()` lets us create methods that return specific results, or expect to be called a particular way, on the fly.

```
> from unittest.mock import *  
> mock = MagicMock()
```

Mocks in Python (2)

- ▶ Once we have called our `mock()` object, the fact that it has been called is recorded.
- ▶ We then (before the test ends) *assert* what we expect to have happened (e.g. that the method was called)
- ▶ If not, then an exception will be raised.
- ▶ Much more complex behaviour can be created – check the API for details.

Testable documentation

- ▶ We have said that sometimes, tests are the best documentation of an API (since documentation often gets out of date)
- ▶ *Testable documentation* frameworks ensure that documentation is kept up to date with code – tests are generated from the documentation of an API.
- ▶ One example, from the Python language, is the `doctest` library.
- ▶ A good API will often give *examples* of how methods are functions should be called, and the Python `doctest` module allows these examples to be extracted and run as tests.

Testable documentation vs unit testing

- ▶ The purpose of these is to ensure that the *documentation examples are still correct*.
- ▶ This is *not* the same as unit testing – doctests will usually only exercise a small number of examples, and are not nearly as thorough as unit tests should be.

Doctest example

```
def square(x):  
    """Return the square of x.  
  
    >>> square(2)  
    4  
    >>> square(-2)  
    4  
    """  
  
    return x * x  
  
if __name__ == '__main__':  
    import doctest  
    doctest.testmod()
```

Doctest in other languages

- ▶ Like xUnit, doctest has been ported to a great many other languages.
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 - ▶ Java has JDoctest
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 - ▶ Ruby has `rdoctest`

Property-based testing

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- ▶ This sort of testing originates from the Haskell testing framework QuickCheck, and is sometimes called *generative testing*
- ▶ Our tests are of the form:

for all data or parameters that are generated in a particular way,
the function or method should produce the following results.

Simple example

- ▶ The “tail” function, applied to a list, returns everything but the first element –
what invariants hold?

Simple example

- ▶ The “tail” function, applied to a list, returns everything but the first element –
what invariants hold?
- ▶ We know that if tail is called on a non-empty list, the length of the result is one less than the length of the list passed in.

Use for interfaces and sub-classes

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- ▶ Our documentation states that all subclasses of a class should maintain some invariant;
the property-based test checks whether it can find counterexamples.

Summary of test types so far

Unit tests provide a way of identifying ways in which a software component deviates from its specification.

Test doubles provide a way of testing a unit of code, even when it depends on other code.

Testable documentation provides a way of testing examples written in the *documentation* for a system, and making sure they still hold.

Property-based testing provides a way of finding counterexamples to any *invariants* we think should hold about a software component.

References

- ▶ Cohn, Mike. *Succeeding with Agile: Software Development Using Scrum*. Upper Saddle River, NJ: Addison-Wesley Professional, 2009.
- ▶ Vocke, Ham. "The Practical Test Pyramid." MartinFowler.com. February 26, 2018. <https://martinfowler.com/articles/practical-test-pyramid.html>.