Software Testing, Quality Assurance & Maintenance—Lecture 3

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Kinds of Assertions

Three built-in choices:

1. assertTrue(aBooleanExpression)
2. assertEquals(expected, actual)
3. assertEquals(expected, actual, tolerance)

note: `assertTrue` can give
hard-to-diagnose error messages
(must try harder when using).

Using Assertions

Assertions are good:

- to check all things that should be true
  (more = better)
- to serve as documentation:
  when system in state S_1,
  and I do X,
  assert that the result should be R, and
  that system should be in S_2.
- to allow failure diagnosis
  (include assertion messages!)

Not Using Assertions

Can also do external result verification:

Write output to files, diff (or custom diff) expected and actual output.

Twist: expected result then not visible when looking at test.

(What's a good workaround?)

Verifying Behaviour

Observe actions (calls) of the SUT.

- procedural behaviour verification; or, (challenge: recording & verifying behaviour)
- via expected behaviour specification. (also captures outbound calls of SUT)

Part I

Mock Objects

John Tenniel's original (1865) illustration for Lewis Carroll's "Alice in Wonderland". Alice sitting between Gryphon and Mock turtle.

Things like mocks

- dummy objects: don't do anything; are like `null` or `None`,
  but pass nullness checks.
- fake objects: have actual (correct) behaviour,
  but unsuitable for production, e.g. in-memory db.
- stubs: produce canned answers.
- mocks: produce canned answers,
  but also check the interaction protocol.

Mock Objects: Email Sender

```
// state or behaviour verification?
public class MailServiceFake
                    implements MailService {
  private List<Message> messages =
      new ArrayList<Message>();

  public void send (Message msg) {
    messages.add(msg);
  }
  public int numberSent() {
    return messages.size();
  }
}
```

Mock Objects: Behaviour Verification

```
// jMock syntax
class OrderInteractionTester... {
  public void testOrderSendsMailIfUnfilled() {
    Order order = new Order(TALISKER, 51);
    Mock warehouse = mock(Warehouse.class); // (1)
    Mock mailer = mock(MailService.class);
    order.setMailer((MailService) mailer.proxy());

    mailer.expects(once()).method("send"); // (2)
    warehouse.expects(once()).method("hasInventory")
      .withAnyArguments()
      .will(returnValue(false));

    order.fill((Warehouse) warehouse.proxy());
  }
}
```

Mock Objects: Document Management

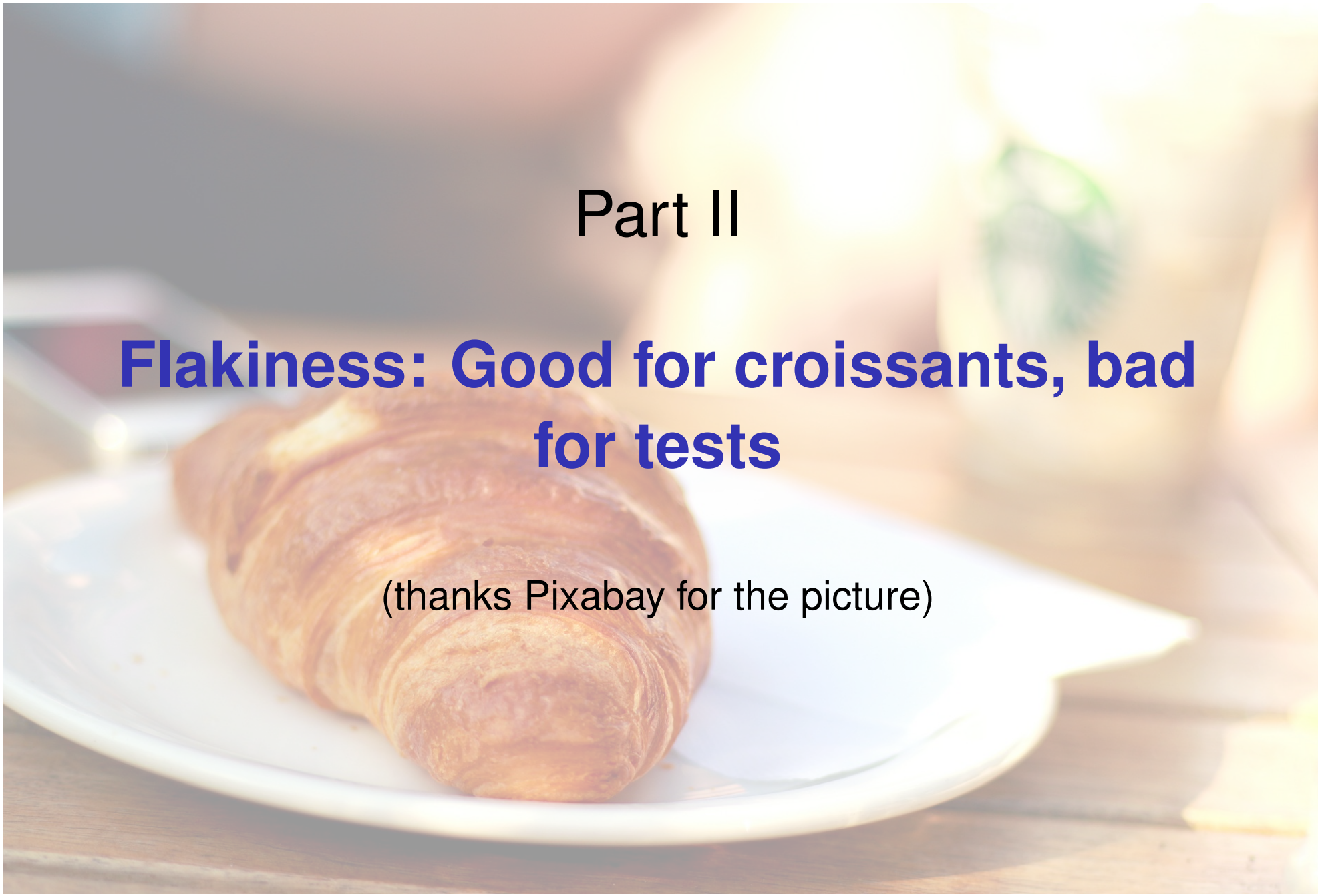
```
// EasyMock syntax
@RunWith(EasyMockRunner.class)
public class ExampleTest {
   @TestSubject
   private ClassUnderTest classUnderTest =
        new ClassUnderTest();

   @Mock // creates a mock object
   private Collaborator mock;

   @Test
   public void testRemoveNonExistingDocument() {
      replay(mock);
      classUnderTest.removeDocument
           ("Does not exist");
   }
}
```

Mock Objects: Using a Mock

```
@Test
public void testAddDocument() {
  // ** recording phase **
  // expect document addition
  mock.documentAdded("Document");
  // expect to be asked to vote for document removal,
  expect(mock.voteForRemoval("Document"))
                .andReturn((byte) 42);
  // expect document removal
  mock.documentRemoved("Document");
  replay(mock);
  // ** replaying phase **
  // we expect the recorded actions to happen
  classUnderTest.addDocument("New Document",
      new byte[0]);
  // check that the behaviour actually happened:
  verify(mock);
```



Part II

Flakiness: Good for croissants, bad for tests

(thanks Pixabay for the picture)

Dealing with Flakiness

There are mitigations:

- label known-flaky tests and rerun them
- ignore or remove flaky tests

They're not great.

Takes a long time to re-run tests.

Causes of Flakiness

Luo et al studied 201 fixes to flaky tests in open-source projects. Fixable causes:

- improper waits for asynchronous responses;
- concurrency; and
- test order dependency.

Asynchronous waits

Typically: a `sleep()` call which didn't wait long enough.

Best practice:

- use some sort of `wait()` call to wait for the result, instead of hardcoding a sleep time.

Concurrency

The usual (see CS343 for more):

- data races;
- atomicity violations;
- deadlocks.

Test order dependency

- Test A expects test B to have already executed
  (and to have left a side effect, e.g. a file).

Especially common in the transition from Java 6 to Java 7, because the test execution order changed.

Solution: remove the dependency.

Plan

More on testing (when to stop?).

Then, mutation analysis (are your tests actually good?).

Part III

When to stop?
Idea 1: Coverage

How many tests?

Do you have enough tests? How do you know?

Test all inputs?

State-of-the-industry: code coverage—

statement coverage, branch coverage.

Side note: white-box and black-box

When you write tests:

White-box testing: you can look at the code;

Black-box testing: you can't look at the code.

Control-Flow Graphs

Mostly people use lines of source code to evaluate coverage, but then your coverage depends on newlines.

It is possible to be more precise and use control-flow graphs, but we won't, this time.

Statement and Branch Coverage

Given a test suite and a program,
instrument the program to:

- count whether each statement (CFG node) is executed;
- count whether each branch (CFG edge) is taken.

Statement coverage is the fraction of statements (nodes) that are executed by the test suite.

Branch coverage is the fraction of branches (edges) that are executed.

Example Code

```
class Foo:
  def m(self, a, b):
    if a < 0 and b < 0:
      return 4
    elif a < 0 and b > 0:
      return 3
    elif a > 0 and b < 0:
      return 2
    elif a >= 0 and b >= 0:
      return a/b
    raise Exception("I■didn't■think■things■through")
```

Example Test Suite

```
import unittest

from .foo import Foo

class CoverageTests(unittest.TestCase):
    def test_one(self):
        f = Foo()
        f.m(1, 2)

    def test_two(self):
        f = Foo()
        f.m(1, -2)

    def test_three(self):
        f = Foo()
        f.m(-1, 2)
```

Coverage Report

```
Name                    Stmts   Miss  Branch  BrPart  Cover   Missing
-------------------------------------------------------------------
l03/foo.py                 11      2       8       2    79%   4, 11
l03/test_suite.py          12      0       0       0   100%
-------------------------------------------------------------------
TOTAL                     124     98      46       2    21%
```

HTML report also available.

On Coverage

Can add missing test cases to visit all lines.

Even with 100% branch coverage,
one is missing an important behaviour: what if `b` is 0?

Collecting Coverage Information

How to collect coverage info? Different in different languages.

- C: recompile with instrumentation
- Java: virtual machine can collect
- Python: provides hooks

Tracking Python Coverage in Python

Use `sys.settrace(f)` to register `f` as a tracing function.
You can find this tracing function in `code/L03/tracing.py`:

```
def traceit(frame: FrameType, event: str, arg: Any)
                                    -> Optional[Callable]:
    if event == 'line':
        global coverage
        function_name = frame.f_code.co_name
        lineno = frame.f_lineno
        coverage.append(lineno)

    return traceit
```

It records the lines that have been executed in variable `coverage`.

Example: using traceit

There is also a function `cgi_decode()` from The Fuzzing Book which I've included in the repo.
We can activate tracing as follows:

```
def cgi_decode_traced(s: str) -> None:
    global coverage
    coverage = []
    sys.settrace(traceit)  # tracing on
    cgi_decode(s)
    sys.settrace(None)     # tracing off
```

and if we call it and print out the coverage, we get something like:

```
>>> cgi_decode_traced("a+b")
>>> print(coverage)
[12, 13, 12, 13, 12, 13, 12, 13, 12, 13, 12, 14, 12, 14, 12
```

Python trick: using with

Cleaner:

```
with Coverage() as cov:
    function_to_be_traced()
c = cov.coverage()
```

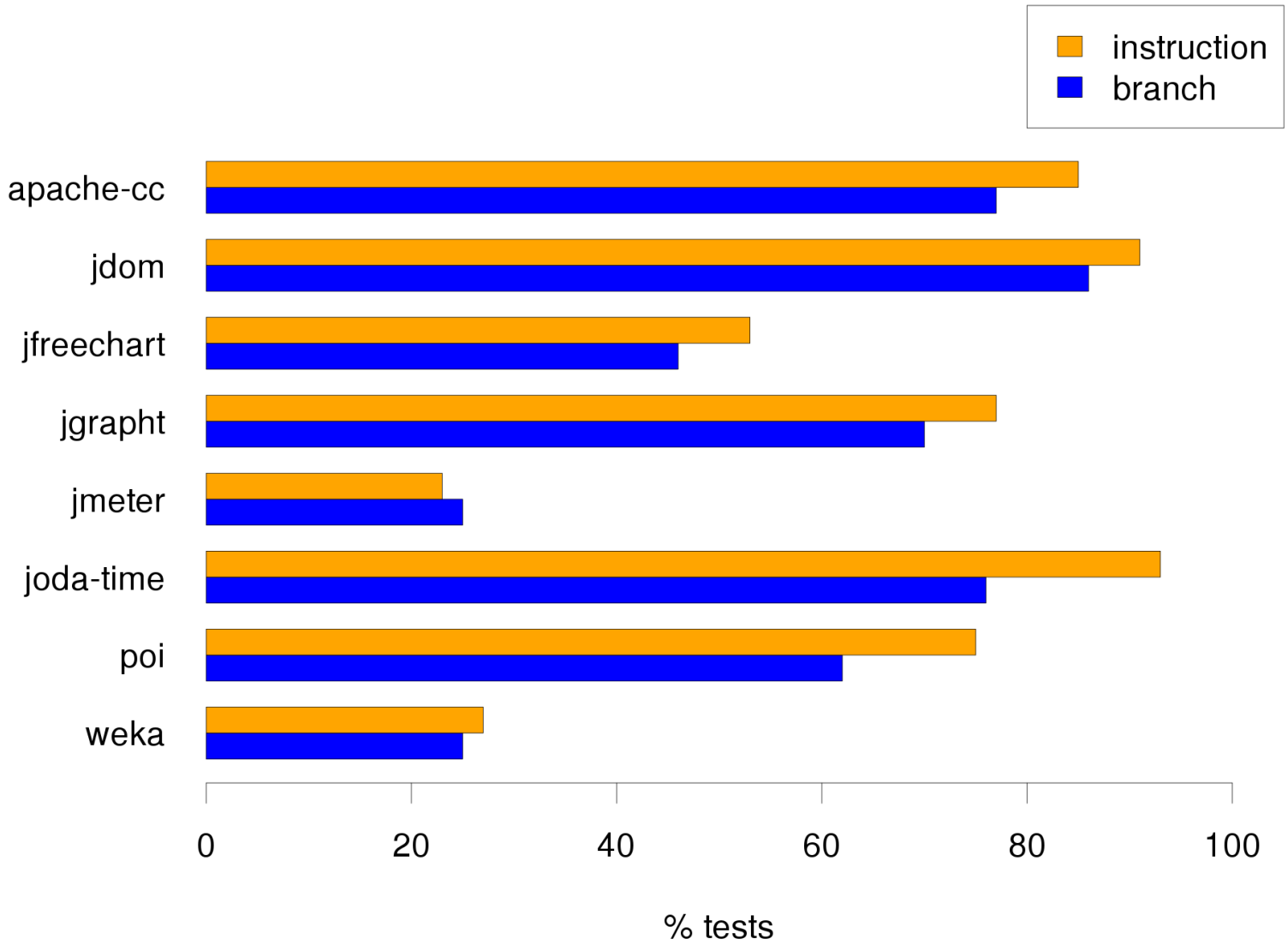
Also, Python introspection can retrieve source code and pretty-print it, highlighting non-covered lines.

This allows you to write tests to cover these lines.

Infeasible Test Requirements

Infeasible to reach 100% coverage on real programs.
How much is enough, and why is there a gap?

Some Real Coverage Data



Case Study: JUnit (4.11) the Artifact

https://avandeursen.com/2012/12/21/line-coverage-lessons-from-junit/

JUnit Measurements

Coverage Report - All Packages

Package	# Classes	Line Coverage		Branch Coverage		Complexity
All Packages	221	84%	2970/3513	81%	859/1060	1.727
junit.extensions	6	82%	52/63	87%	7/8	1.25
junit.framework	17	76%	399/525	90%	139/154	1.605
junit.runner	3	49%	77/155	41%	23/56	2.225
junit.textui	2	76%	99/130	76%	23/30	1.686
org.junit	14	85%	196/230	75%	68/90	1.655
org.junit.experimental	2	91%	21/23	83%	5/6	1.5
org.junit.experimental.categories	5	100%	67/67	100%	44/44	3.357
org.junit.experimental.max	8	85%	92/108	86%	26/30	1.969
org.junit.experimental.results	6	92%	37/40	87%	7/8	1.222
org.junit.experimental.runners	1	100%	2/2	N/A	N/A	1
org.junit.experimental.theories	14	96%	119/123	88%	37/42	1.674
org.junit.experimental.theories.internal	5	88%	98/111	92%	39/42	2.29
org.junit.experimental.theories.suppliers	2	100%	7/7	100%	2/2	2
org.junit.internal	11	94%	149/157	94%	53/56	1.947
org.junit.internal.builders	8	98%	57/58	92%	13/14	2
org.junit.internal.matchers	4	75%	40/53	0%	0/18	1.391
org.junit.internal.requests	3	96%	27/28	100%	2/2	1.429
org.junit.internal.runners	18	73%	306/415	63%	82/130	2.155
org.junit.internal.runners.model	3	100%	26/26	100%	4/4	1.5
org.junit.internal.runners.rules	1	100%	35/35	100%	20/20	2.111
org.junit.internal.runners.statements	7	97%	92/94	100%	14/14	2
org.junit.matchers	1	9%	1/11	N/A	N/A	1
org.junit.rules	20	89%	203/226	96%	31/32	1.444
org.junit.runner	12	93%	150/161	88%	30/34	1.378
org.junit.runner.manipulation	9	85%	36/42	77%	14/18	1.632
org.junit.runner.notification	12	100%	98/98	100%	8/8	1.162
org.junit.runners	16	98%	321/327	96%	95/98	1.737
org.junit.runners.model	11	82%	163/198	73%	73/100	1.918

Report generated by Cobertura 1.9.4.1 on 12/22/12 2:25 PM.

JUnit Stats

Overall instruction coverage: 85%.

13,000 lines of code, 15,000 lines of test.

Consistent with industry average.

What's not covered? Deprecation

- deprecated code: 65% instruction coverage
- nondeprecated code: 93% instruction coverage

- newer code (in `org.junit.*`): 90% instruction coverage
- older code (in `junit.*`): 70% instruction coverage

(Why is this? Perhaps the coverage decreased over time for the deprecated code, since no one is really maintaining it anymore, and failing test cases just get removed.)

A Whole Untested Class

Blogpost author found one class that was completely untested!

There were tests.
But the tests never got run, because they were never added to CI.

They also failed when run. (You don't run it, it doesn't work.)

The Usual Suspects 1: Too Simple to Test

```
public static void assumeFalse(boolean b) {
  assumeTrue(!b);
}

/**
* Override to set up your specific external reso
*
* @throws if setup fails (which will disable {@c
*/
protected void before() throws Throwable {
  // do nothing
}
```

The Usual Suspects 2: Dead by Design

```
/**
* Protect constructor since it is a static only
*/
protected Assert() { }

// should never be executed:
catch (InitializationError e) {
  throw new RuntimeException(
  "Bug in saff's brain: " +
  "Suite constructor, called as above, should alw
}

// unreachable
try {
  ...
} catch (InitializationError e) {
  return new ErrorReportingRunner(null, e); // u
}
```

Thoughts on JUnit Coverage

JUnit: written by people who care about testing.

Non-deprecated code: 93% instruction coverage,
i.e. $\leq$ 2–3 untested lines of code per method.

Probably OK to have lower coverage for deprecated code.

Don't forget that what is in the tests matters too!