CSE 403
Lecture 12

Effective Unit Testing

Reading:

The Art of Unit Testing, Ch. 7 (Osherove)

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http://www.cs.washington.edu/403/

Bugs and testing

- **software reliability**: Probability that a software system will not cause failure under specified conditions.
  - measured by uptime, MTTF (mean time till failure), crash data

- **bugs** are inevitable in any complex software system
  - industry estimates: 10-50 bugs per 1000 lines of code
  - a bug can be visible or can hide in your code until much later

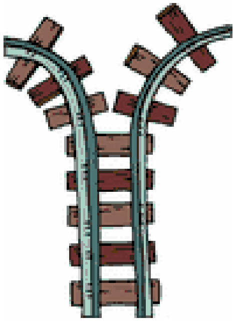
- **testing**: A systematic attempt to reveal errors.
  - failed test: an error was demonstrated
  - passed test: no error was found (for this particular situation)

Difficulties of testing

- perception by some developers and managers
  - testing is seen as a novice's job
  - assigned to the least experienced team members
  - done as an afterthought (if at all)

- limitations of what testing can show you
  - it is impossible to completely test a system
  - testing does not always directly reveal the actual bugs in the code
  - testing does not show absence of errors in software

Faults and errors



- **error**: incorrect software behavior
  - *example: Message box said, "Welcome, null!"*
- **fault**: mechanical or algorithmic cause of error (bug)
  - *example: Account name field is not set properly.*
  - Requirements specify desired behavior;
    if the system deviates from that, it has a fault.

Quality control techniques

- **fault avoidance**: Prevent errors before system is released.
  - reviews, inspections, walkthroughs,
    development methodologies, configuration management

- **fault tolerance**: When system can recover by itself.
  - rollbacks, redundancy, mirroring

- **fault detection**: Find faults without recovering from them.
  - debugging, <u>**testing**</u>

Some kinds of testing

- **unit testing**: Looks for errors in subsystems in isolation.

- **integration testing**: find errors when connecting subsystems
  - bottom-up: integrate upward into double, triple, quadruple test
  - top-down: test UI first, then add layers to replace stubs
  - stub/mock: an incomplete object/subsystem in masquerade

- **system testing**: test entire system behavior as a whole, with respect to scenarios and requirements
  - functional testing: test whether system meets requirements
  - performance, load, stress testing
  - acceptance, usability, installation, beta testing

Unit testing

- **unit testing**: Looks for errors in subsystems in isolation.
  - generally a "subsystem" means a class or object

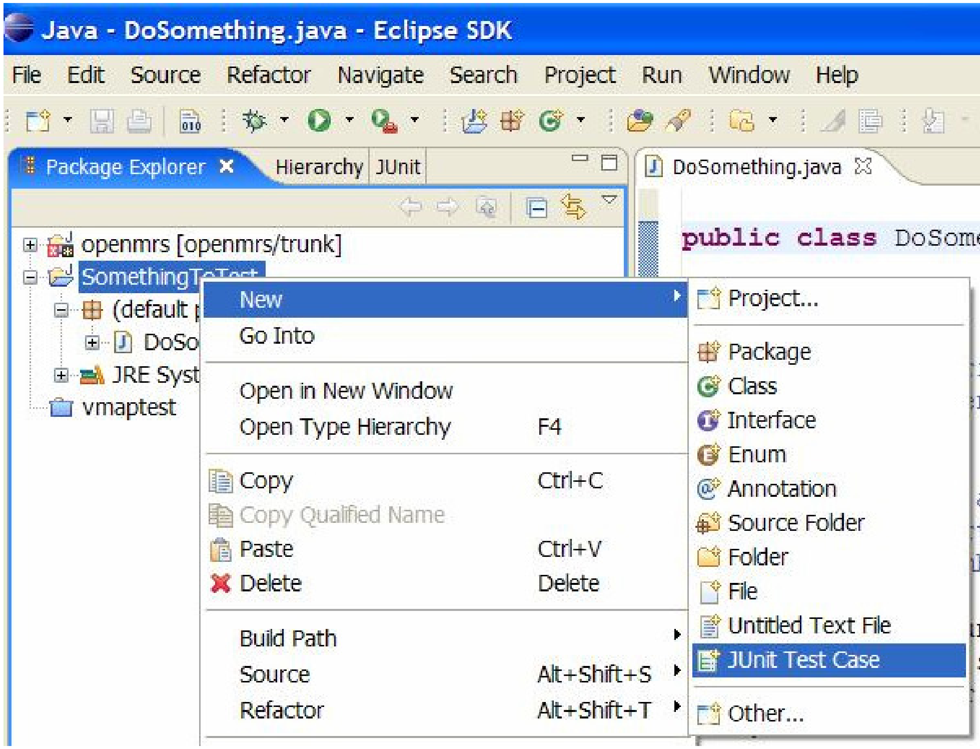
- benefits:
  1. reduces number of things to test
  2. easier to find faults when errors occur
  3. can test many components in parallel

- In principle, test all objects.
  - Because of time, test important ones involved in use cases.

JUnit and Eclipse

- Adding JUnit to an Eclipse project:
  - click **Project** → **Properties** → **Add External JARs...** → *eclipse folder* / plugins / org.junit_*x.x.x* / junit.jar

- Create a test case
  - click **File** → **New** → **JUnit Test Case**
  - or right-click a file and choose **New Test**
  - Eclipse can create stubs of method tests for you



```
public class DoSome
```

JUnit assertion methods

- `assertTrue` (***message***, **test**) (italic = *optional*)
- `assertFalse` (***message***, **test**)

- `assertEquals` (***message***, **expected**, **actual**)
- `assertNotEquals` (***message***, **expected**, **actual**)

- `assertSame` (***message***, **expected**, **actual**)
- `assertNotSame` (***message***, **expected**, **actual**)

  compares with `==`

- `assertNull` (***message***, **obj**)
- `assertNotNull` (***message***, **obj**)

- `fail` (***message***)
  - causes the test to immediately fail (why no `pass` method?)

Ruby's Test::Unit

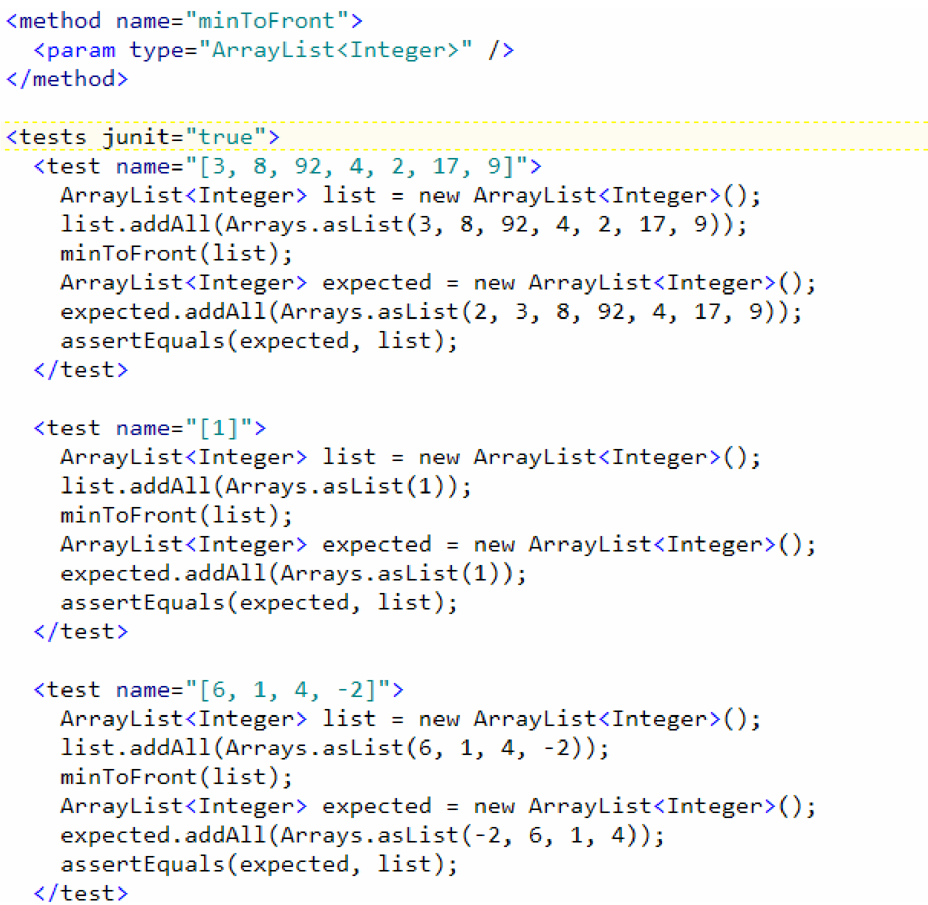
```
require 'test/unit'

class name < Test::Unit::TestCase
    def setup
        ...
    end

    def teardown
        ...
    end

    def name    # a test case
        ...
        assert(condition, message)
    end
end
```

Ruby assertions

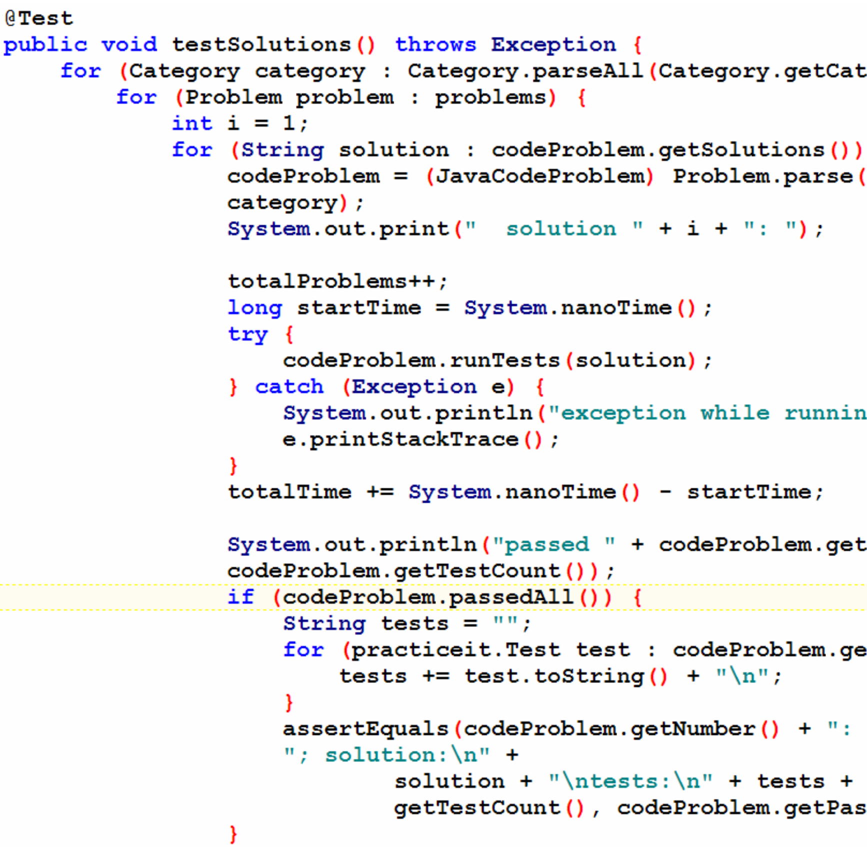
- `assert(boolean, [msg])` - ensures the object/expression is true
- `assert_equal(obj1, obj2, [msg])` - ensures obj1 obj2 is true
- `assert_not_equal(obj1, obj2, [msg])` - ensures obj1 obj2 is false
- `assert_same(obj1, obj2, [msg])` - ensures obj1.equal?(obj2) is true
- `assert_not_same(obj1, obj2, [msg])` - ensures obj1.equal?(obj2) is false
- `assert_nil(obj, [msg])` - ensures obj.nil? is true
- `assert_not_nil(obj, [msg])` - ensures obj.nil? is false
- `assert_match(regexp, string, [msg])` - ensures a string matches the regular expression
- `assert_no_match(regexp, string, [msg])` - ensures string doesn't match regex
- `assert_in_delta(expecting, actual, delta, [msg])` - ensures numbers are within delta
- `assert_throws(symbol, [msg]) { block }` - ensures a block throws the symbol
- `assert_raises(exceptions) { block }` - ensures block raises an exception
- `assert_nothing_raised(exceptions) { block }` - a block doesn’t raise the exceptions
- `assert_instance_of(class, obj, [msg])` - ensures obj is the class type
- `assert_kind_of(class, obj, [msg])` - ensures obj is or descends from class
- `assert_respond_to(obj, symbol, [msg])` - ensures obj has a method called symbol
- `assert_operator(obj1, operator, obj2, [msg])` - ensures obj1.operator(obj2) is true
- `assert_send(array, [msg])` - ensures that executing method listed in array[1] on the object in array[0] with parameters of array[2+] is true
- `flunk([msg])` - Forcibly fails this test

Unit tests in Practice-It

- the system tests submitted student code using JUnit
- the system (written in Java/JSP) also tests itself using JUnit



```
<method name="minToFront">
  <param type="ArrayList<Integer>" />
</method>

<tests junit="true">
  <test name="[3, 8, 92, 4, 2, 17, 9]">
    ArrayList<Integer> list = new ArrayList<Integer>();
    list.addAll(Arrays.asList(3, 8, 92, 4, 2, 17, 9));
    minToFront(list);
    ArrayList<Integer> expected = new ArrayList<Integer>();
    expected.addAll(Arrays.asList(2, 3, 8, 92, 4, 17, 9));
    assertEquals(expected, list);
  </test>

  <test name="[1]">
    ArrayList<Integer> list = new ArrayList<Integer>();
    list.addAll(Arrays.asList(1));
    minToFront(list);
    ArrayList<Integer> expected = new ArrayList<Integer>();
    expected.addAll(Arrays.asList(1));
    assertEquals(expected, list);
  </test>

  <test name="[6, 1, 4, -2]">
    ArrayList<Integer> list = new ArrayList<Integer>();
    list.addAll(Arrays.asList(6, 1, 4, -2));
    minToFront(list);
    ArrayList<Integer> expected = new ArrayList<Integer>();
    expected.addAll(Arrays.asList(-2, 6, 1, 4));
    assertEquals(expected, list);
  </test>
```

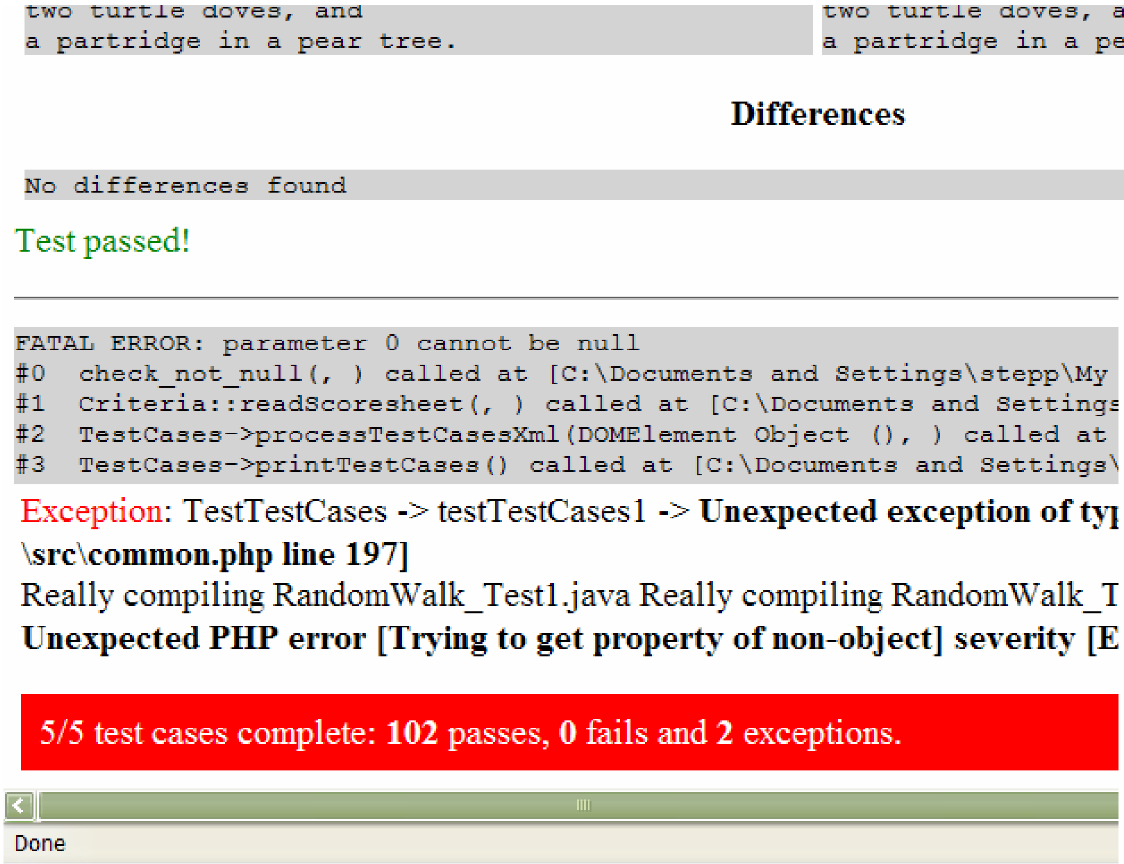


```
@Test
public void testSolutions() throws Exception {
    for (Category category : Category.parseAll(Category.getCat
        for (Problem problem : problems) {
            int i = 1;
            for (String solution : codeProblem.getSolutions())
                codeProblem = (JavaCodeProblem) Problem.parse(
                category);
                System.out.print("  solution " + i + ": ");

                totalProblems++;
                long startTime = System.nanoTime();
                try {
                    codeProblem.runTests(solution);
                } catch (Exception e) {
                    System.out.println("exception while runnin
                    e.printStackTrace();
                }
                totalTime += System.nanoTime() - startTime;

                System.out.println("passed " + codeProblem.get
                codeProblem.getTestCount());
                if (codeProblem.passedAll()) {
                    String tests = "";
                    for (practiceit.Test test : codeProblem.ge
                        tests += test.toString() + "\n";
                    }
                    assertEquals(codeProblem.getNumber() + ":
                    "; solution:\n" +
                            solution + "\ntests:\n" + tests +
                            getTestCount(), codeProblem.getPas
                }
```

Unit tests in Grade-It

– grading scripts test student homework using JUnit test cases

– the web grading system tests itself using PHPunit/Simpletest



```
two turtle doves, and
a partridge in a pear tree.
```

```
two turtle doves, a
a partridge in a pe
```

Differences

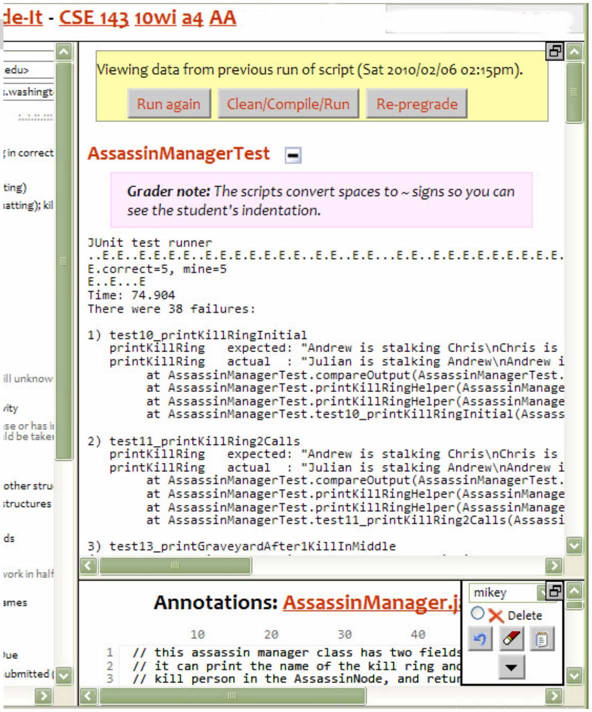
```
No differences found
```

Test passed!

```
FATAL ERROR: parameter 0 cannot be null
#0  check_not_null(, ) called at [C:\Documents and Settings\stepp\My
#1  Criteria::readScoresheet(, ) called at [C:\Documents and Settings
#2  TestCases->processTestCasesXml(DOMElement Object (), ) called at
#3  TestCases->printTestCases() called at [C:\Documents and Settings\
```

Exception: TestTestCases -> testTestCases1 -> **Unexpected exception of ty**
\src\common.php line 197]
Really compiling RandomWalk_Test1.java Really compiling RandomWalk_T
Unexpected PHP error [Trying to get property of non-object] severity [E

5/5 test cases complete: **102** passes, **0** fails and **2** exceptions.



Viewing data from previous run of script (Sat 2010/02/06 02:15pm).

AssassinManagerTest

***Grader note:** The scripts convert spaces to ~ signs so you can see the student's indentation.*

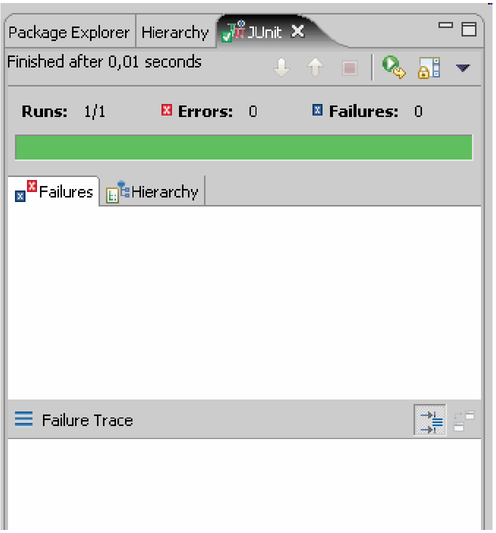
```
JUnit test runner
..E.E..E.E.E.E..E.E.E.E.E.E.E..E.E..E.E...E.E..E.E.E.E.E.E.E.E.
E.correct=5, mine=5
E..E...E
Time: 74.904
There were 38 failures:

1) test10_printKillRingInitial
   printKillRing   expected: "Andrew is stalking Chris\nChris is
   printKillRing   actual  : "Julian is stalking Andrew\nAndrew i
        at AssassinManagerTest.compareOutput(AssassinManagerTest.
        at AssassinManagerTest.printKillRingHelper(AssassinManage
        at AssassinManagerTest.printKillRingHelper(AssassinManage
        at AssassinManagerTest.test10_printKillRingInitial(Assass

2) test11_printKillRing2Calls
   printKillRing   expected: "Andrew is stalking Chris\nChris is
   printKillRing   actual  : "Julian is stalking Andrew\nAndrew i
        at AssassinManagerTest.compareOutput(AssassinManagerTest.
        at AssassinManagerTest.printKillRingHelper(AssassinManage
        at AssassinManagerTest.printKillRingHelper(AssassinManage
        at AssassinManagerTest.test11_printKillRing2Calls(Assassi

3) test13_printGraveyardAfter1KillInMiddle
```

Annotations: AssassinManager.j

```
// this assassin manager class has two fields
// it can print the name of the kill ring and
// kill person in the AssassinNode, and retur
```

Qualities of good tests

- test cases free of bugs
  - a broken test isn't much help
- readable test case code
- easy to add/update tests
- easy/fast to run
  - unit tests are often run on
    each build or checkin, so fast = good



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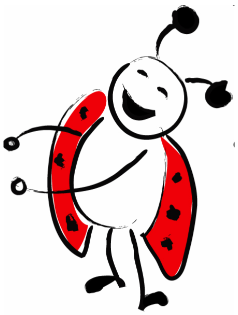
Runs: 1/1 Errors: 0 Failures: 0



Bugs in tests

- hard to find
  - developers assume that tests are correct
- manifest in odd ways
  - sometimes test initially passes, then begins to fail much later
    - code under test may have been altered in a subtle way
    - test case may have relied on invalid assumptions
    - API of code under test may have changed
- often test wasn't written by developer
  - bug assigned back and forth

What's wrong with this?

```
public class DateTest {
    @Test
    public void test1() {
        Date d = new Date(2050, 2, 15);
        d.addDays(4);
        assertEquals(d.getYear(), 2050);
        assertEquals(d.getMonth(), 2);
        assertEquals(d.getDay(), 19);
    }

    @Test
    public void test2() {
        Date d = new Date(2050, 2, 15);
        d.addDays(14);
        assertEquals(d.getYear(), 2050);
        assertEquals(d.getMonth(), 3);
        assertEquals(d.getDay(), 1);
    }
}
```

Well-structured assertions

```
public class DateTest {
    @Test
    public void test1() {
        Date d = new Date(2050, 2, 15);
        d.addDays(4);
        assertEquals(2050, d.getYear());  // expected
        assertEquals(2, d.getMonth());    // value should
        assertEquals(19, d.getDay());     // be at LEFT
    }

    @Test
    public void test2() {
        Date d = new Date(2050, 2, 15);
        d.addDays(14);
        assertEquals("year after +14 days", 2050, d.getYear());
        assertEquals("month after +14 days", 3, d.getMonth());
        assertEquals("day after +14 days", 1, d.getDay());
    }   // test cases should usually have messages explaining
}       // what is being checked, for better failure output
```

Expected answer objects

```
public class DateTest {
    @Test
    public void test1() {
        Date d = new Date(2050, 2, 15);
        d.addDays(4);
        Date expected = new Date(2050, 2, 19);
        assertEquals(expected, d);  // use an expected answer
    }                               // object to minimize tests

                                    // (Date must have toString
    @Test                           //  and equals methods)
    public void test2() {
        Date d = new Date(2050, 2, 15);
        d.addDays(14);
        Date expected = new Date(2050, 3, 1);
        assertEquals("date after +14 days", expected, d);
    }
}
```

Pervasive timeouts

```
public class DateTest {
    @Test(timeout = DEFAULT_TIMEOUT)
    public void test1() {
        Date d = new Date(2050, 2, 15);
        d.addDays(4);
        Date expected = new Date(2050, 2, 19);
        assertEquals("date after +4 days", expected, d);
    }


    @Test(timeout = DEFAULT_TIMEOUT)
    public void test2() {
        Date d = new Date(2050, 2, 15);
        d.addDays(14);
        Date expected = new Date(2050, 3, 1);
        assertEquals("date after +14 days", expected, d);
    }

    // almost every test should have a timeout so it can't
    // lead to an infinite loop; good to set a default, too
    private static final int DEFAULT_TIMEOUT = 2000;
}
```

Naming test cases

```
public class DateTest {
    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_withinSameMonth_1() {
        Date actual = new Date(2050, 2, 15);
        actual.addDays(4);
        Date expected = new Date(2050, 2, 19);
        assertEquals("date after +4 days", expected, actual);
    }
    // give test case methods really long descriptive names

    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_wrapToNextMonth_2() {
        Date actual = new Date(2050, 2, 15);
        actual.addDays(14);
        Date expected = new Date(2050, 3, 1);
        assertEquals("date after +14 days", expected, actual);
    }
    // give descriptive variable names to expected/actual values


    private static final int DEFAULT_TIMEOUT = 2000;
}
```

Squashing redundancy

```
public class DateTest {
    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_withinSameMonth_1() {
        addHelper(2050, 2, 15, +4, 2050, 2, 19);
    }

    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_wrapToNextMonth_2() {
        addHelper(2050, 2, 15, +14, 2050, 3, 1);
    }

    // use lots of helpers to make actual tests extremely short
    private void addHelper(int y1, int m1, int d1, int add,
                           int y2, int m2, int d2) {
        Date actual = new Date(y, m, d);
        actual.addDays(add);
        Date expect = new Date(y2, m2, d2);
        assertEquals("after +" + add + " days", expect, actual);
    }

    // can also use "parameterized tests" in some frameworks
    ...
```

Flexible helpers

```
public class DateTest {
    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_multipleCalls_wrapToNextMonth2x() {
        Date d = addHelper(2050, 2, 15, +14, 2050, 3, 1);
        addhelper(d, +32, 2050, 4, 2);
        addhelper(d, +98, 2050, 7, 9);
    }

    // Helpers can box you in; hard to test many calls/combine.
    // Create variations that allow better flexibility
    private Date addHelper(int y1, int m1, int d1, int add,
                           int y2, int m2, int d2) {
        Date date = new Date(y, m, d);
        addHelper(date, add, y2, m2, d2);
        return d;
    }

    private void addHelper(Date date, int add,
                           int y2, int m2, int d2) {
        date.addDays(add);
        Date expect = new Date(y2, m2, d2);
        assertEquals("date after +" + add + " days", expect, d);
    }
```

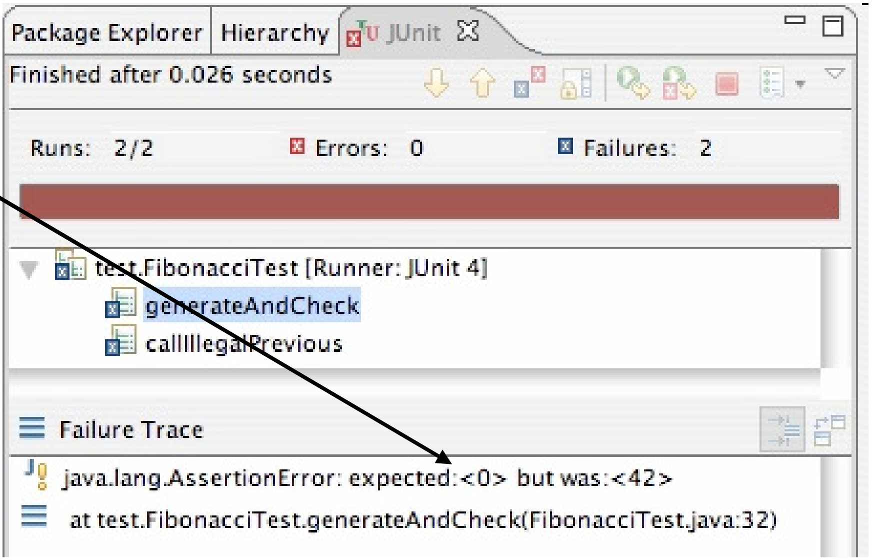
What's wrong with this?

```
public class DateTest {
    @Test
    public void test_addDays_addJustOneDay_1() {
        Date actual = new Date(2050, 2, 15);
        actual.addDays(1);
        Date expected = new Date(2050, 2, 16);
        assertEquals("after adding one day to 2050/2/15,\n" +
            "should have gotten " + expected + "\n" +
            " but instead got " + actual\n",
            expected, actual);
    }
    ...
}
```

Good assertion messages

```
public class DateTest {
    @Test
    public void test_addDays_addJustOneDay_1() {
        Date actual = new Date(2050, 2, 15);
        actual.addDays(1);
        Date expected = new Date(2050, 2, 16);
        assertEquals("add one day to 2050/2/15",
            expected, actual);
    }
    ...
}

// JUnit will already show
// the expected and actual
// values in its output;
//
// don't need to repeat them
// in the assertion message
```



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Runs: 2/2   Errors: 0   Failures: 2

test.FibonacciTest [Runner: JUnit 4]
generateAndCheck
callIllegalPrevious

Failure Trace

```
java.lang.AssertionError: expected:<0> but was:<42>
at test.FibonacciTest.generateAndCheck(FibonacciTest.java:32)
```

What's wrong with this?

```
public class DateTest {
    // test every day of the year
    @Test
    public void tortureTest() {
        Date date = new Date(2050, 1, 1);
        int month = 1;
        int day = 1;
        for (int i = 1; i < 365; i++) {
            date.addDays(1);
            if (day < DAYS_PER_MONTH[month]) {day++;}
            else                             {month++; day=1;}
            assertEquals(new Date(2050, month, day), date);
        }
    }

    private static final int[] DAYS_PER_MONTH = {
        0, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31
    }; // Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
}
```

Trustworthy tests

- Test one thing at a time per test method.
  - 10 small tests are much better than 1 test 10x as large.

- Each test method should have few (likely 1) assert statements.
  - If you assert many things, the first that fails stops the test.
  - You won't know whether a later assertion would have failed.

- Tests should avoid logic.
  - minimize `if/else`, `loops`, `switch`, etc.
  - avoid `try/catch`
    - If it's supposed to throw, use expected=... if not, let JUnit catch it.

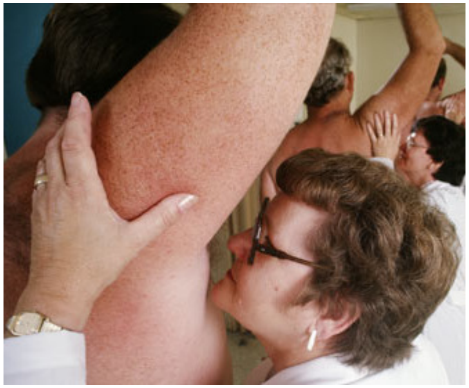
- Torture tests are okay, but only *in addition to* simple tests.

What's wrong with this?

```
public class DateTest {
    // shared Date object to test with (saves memory!!1)
    private static Date DATE;

    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_sameMonth() {
        DATE = new Date(2050, 2, 15);      // first test;
        addhelper(DATE,  +4, 2050, 2, 19);  // DATE = 2/15 here
    }

    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_nextMonthWrap() {   // second test;
        addhelper(DATE, +10, 2050, 3, 1);   // DATE = 2/19 here
    }

    @Test(timeout = DEFAULT_TIMEOUT)
    public void addDays_multipleCalls() {   // third test;
        addDays_sameMonth();                // go back to 2/19;
        addhelper(DATE, +1, 2050, 2, 20);   // test two calls
        addhelper(DATE, +1, 2050, 2, 21);
    }
    ...
}
```

Isolation/order "smells"

- Tests should be self-contained and not care about each other.



- "**Smells**" (bad things to avoid) in tests:
  - *Constrained test order* : Test A must run before Test B. (usually a misguided attempt to test order/flow)
  - *Tests call each other* : Test A calls Test B's method (calling a shared helper is OK, though)
  - *Mutable shared state* : Tests A/B both use a shared object. If A breaks it, what happens to B?

Useful language features

- Elegant tests use the expressive features of your language.

- Java and many languages support variable numbers of params:

```
public void depositAll(Account a, double... amounts) {
    for (double amount : amounts) {
        a.deposit(amount);
    }
}
...

Account a = new Account("Shirley", 10.00);
a.depositAll(4.00, 5.67, 8.90);
a.depositAll(100.50);
```

Tests and data structures

- Need to pass lots of arrays? Use array literals

```
public void exampleMethod(int[] values) { ... }
...
exampleMethod(new int[] {1, 2, 3, 4});
exampleMethod(new int[] {5, 6, 7});
```

- Need a quick `ArrayList`? Try `Arrays.asList`

```
List<Integer> list = Arrays.asList(7, 4, -2, 3, 9, 18);
```

- Need a quick set, queue, etc.? Many collections can take a list

```
Set<Integer> list = new HashSet<Integer>(
                        Arrays.asList(7, 4, -2, 9));
```

More data structures

- Need a quick `Map` or something else? Roll your own helper

```
// pre-populates a map from given keys to given values
public static <K, V> Map<K, V> asMap(List<K> keys,
                                     List<V> values) {
    Map<K, V> map = new HashMap<K, V>();
    for (int i = 0; i < keys.size(); i++) {
        map.put(keys.get(i), values.get(i));
    }
    return map;
}
...

Map<String, Integer> taAges = asMap(
    Arrays.asList("Marty", "Logan", "Kelly", "Marisa"),
    Arrays.asList(23,      14,      39,      25);
);
```