# LECTURE 09: TESTING

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# PLAN

- Unit Testing
- JUnit

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# 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).

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# 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).
    - "My code is good; it won't have bugs.  I don't need to test it."
    - "I'll just find the bugs by running the client program."

- 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 prove the absence of errors in software.

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# Unit testing

- Unit testing: Looking for errors in a subsystem in isolation.
  - Generally a "subsystem" means a particular class or object.
  - The Java library JUnit helps us to easily perform unit testing.


- The basic idea:
  - For a given class Foo, create another class FooTest to test it, containing various "test case" methods to run.
  - Each method looks for particular results and passes / fails.

- JUnit provides "assert" commands to help us write tests.
  - The idea: Put assertion calls in your test methods to check things you expect to be true.  If they aren't, the test will fail.

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# A JUnit test class

```
import org.junit.*;
import static org.junit.Assert.*;

public class name {
    ...

    @Test
    public void name() {   // a test case method
        ...
    }
}
```

– A method with `@Test` is flagged as a JUnit test case.
  • All `@Test` methods run when JUnit runs your test class.

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# JUnit assertion methods

| | |
|---|---|
| `assertTrue(`**test**`)` | fails if the boolean test is `false` |
| `assertFalse(`**test**`)` | fails if the boolean test is `true` |
| `assertEquals(`**expected**`, `**actual**`)` | fails if the values are not equal |
| `assertSame(`**expected**`, `**actual**`)` | fails if the values are not the same (by ==) |
| `assertNotSame(`**expected**`, `**actual**`)` | fails if the values *are* the same (by ==) |
| `assertNull(`**value**`)` | fails if the given value is *not* `null` |
| `assertNotNull(`**value**`)` | fails if the given value is `null` |
| `fail()` | causes current test to immediately fail |

- Each method can also be passed a string to display if it fails:
  - e.g. assertEquals("message", expected, actual)
  - Why is there no pass method?

# ArrayIntList JUnit test

```
import org.junit.*;
import static org.junit.Assert.*;
public class TestArrayIntList {
    @Test
    public void testAddGet1() {
        ArrayIntList list = new ArrayIntList();
        list.add(42);
        list.add(-3);
        list.add(15);
        assertEquals(42, list.get(0));
        assertEquals(-3, list.get(1));
        assertEquals(15, list.get(2));
    }
    @Test
    public void testIsEmpty() {
        ArrayIntList list = new ArrayIntList();
        assertTrue(list.isEmpty());
        list.add(123);
        assertFalse(list.isEmpty());
        list.remove(0);
        assertTrue(list.isEmpty());
    }
    ...
```

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# JUnit exercise

Given a `Date` class with the following methods:

```
– public Date(int year, int month, int day)
– public Date()                          // today
– public int getDay(), getMonth(), getYear()
– public void addDays(int days)          // advances by days
– public int daysInMonth()
– public String dayOfWeek()              // e.g. "Sunday"
– public boolean equals(Object o)
– public boolean isLeapYear()
– public void nextDay()                  // advances by 1 day
– public String toString()
```

- Come up with unit tests to check the following:
  - That no `Date` object can ever get into an invalid state.
  - That the `addDays` method works properly.
    - It should be efficient enough to add 1,000,000 days in a call.

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# 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);
    }
}
```

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# 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
```

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# 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);
    }
}
```

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# Naming test cases

```
public class DateTest {
    @Test
    public void test_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
    public void test_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 names to expected/actual values
}
```

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# 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(
            "should have gotten " + expected + "\n" +
            " but instead got " + actual\n",
            expected, actual);
    }
    ...
}
```

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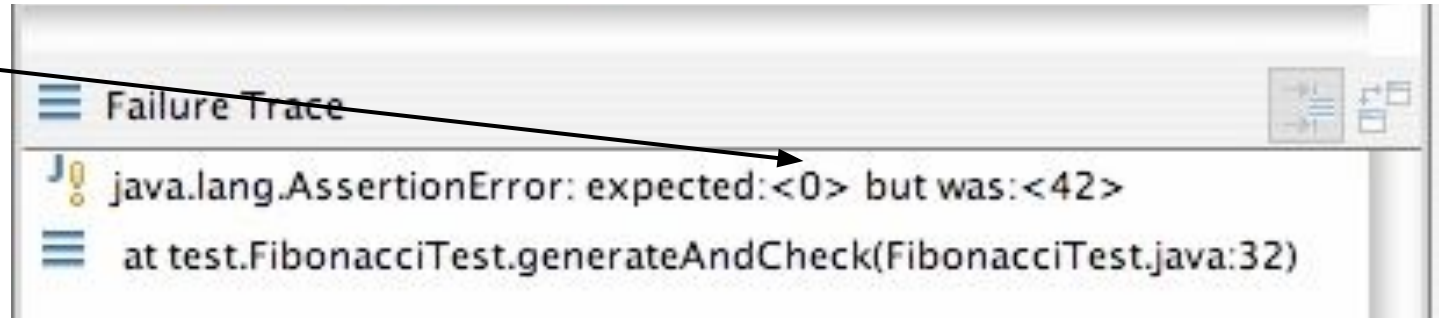
# Good assertion messages

```
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("adding 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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# Tests with a timeout

```
@Test(timeout = 5000)
public void name() { ... }
```

– The above method will be considered a failure if it doesn't finish running within 5000 ms

```
private static final int TIMEOUT = 2000;
...

@Test(timeout = TIMEOUT)
public void name() { ... }
```

– Times out / fails after 2000 ms

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# Pervasive timeouts

```
public class DateTest {
    @Test(timeout = DEFAULT_TIMEOUT)
    public void test_addDays_withinSameMonth_1() {
        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 test_addDays_wrapToNextMonth_2() {
        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;
}
```

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# Testing for exceptions

```
@Test(expected = ExceptionType.class)
public void name() {
    ...
}
```

– Will pass if it *does* throw the given exception.
  - If the exception is *not* thrown, the test fails.
  - Use this to test for expected errors.

```
@Test(expected = ArrayIndexOutOfBoundsException.class)
public void testBadIndex() {
    ArrayIntList list = new ArrayIntList();
    list.get(4);   // should fail
}
```

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# Setup and teardown

```
@Before
public void name() { ... }
@After
public void name() { ... }
```

– methods to run before/after each test case method is called

```
@BeforeClass
public static void name() { ... }
@AfterClass
public static void name() { ... }
```

– methods to run once before/after the entire test class runs

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# Tips for testing

- You cannot test every possible input, parameter value, etc.
  - So you must think of a limited set of tests likely to expose bugs.
- Think about boundary cases
  - positive; zero; negative numbers
  - right at the edge of an array or collection's size
- Think about empty cases and error cases
  - 0, -1, null;  an empty list or array
- Test behavior in combination
  - maybe add usually works, but fails after you call remove
  - make multiple calls;  maybe size fails the second time only

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# What's wrong with this?

```
public class DateTest {
    // test every day of the year
    @Test(timeout = 10000)
    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
}
```

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# 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.

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# JUnit exercise

Given our `Date` class seen previously:

```
– public Date(int year, int month, int day)
– public Date()                          // today
– public int getDay(), getMonth(), getYear()
– public void addDays(int days)    // advances by days
– public int daysInMonth()
– public String dayOfWeek()              // e.g. "Sunday"
– public boolean equals(Object o)
– public boolean isLeapYear()
– public void nextDay()                  // advances by 1 day
– public String toString()
```

- Come up with unit tests to check the following:
  - That no `Date` object can ever get into an invalid state.
  - That the `addDays` method works properly.
    - It should be efficient enough to add 1,000,000 days in a call.

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# 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 act = new Date(y, m, d);
        actual.addDays(add);
        Date exp = new Date(y2, m2, d2);
        assertEquals("after +" + add + " days", exp, act);
    }

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

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# 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);
    }
    ...
```

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# Regression testing

- Regression: When a feature that used to work, no longer works.
  - Likely to happen when code changes and grows over time.
  - A new feature/fix can cause a new bug or reintroduce an old bug.

- Regression testing: Re-executing prior unit tests after a change.
  - Often done by scripts during automated testing.
  - Used to ensure that old fixed bugs are still fixed.
  - Gives your app a minimum level of working functionality.

- Many products have a set of mandatory check-in tests that must pass before code can be added to a source code repository.

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# Test-driven development

- Unit tests can be written after, during, or even before coding.
  - test-driven development: Write tests, then write code to pass them.

- Imagine that we'd like to add a method subtractWeeks to our Date class, that shifts this Date backward in time by the given number of weeks.

- Write code to test this method before it has been written.
  - Then once we do implement the method, we'll know if it works.

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# 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));
```

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# 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);
    }
    ...
}
```

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# Test case "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?)

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# Test suites

- Test suite: One class that runs many JUnit tests.
  - An easy way to run all of your app's tests at once.

```
import org.junit.runner.*;
import org.junit.runners.*;

@RunWith(Suite.class)
@Suite.SuiteClasses({
    TestCaseName.class,
    TestCaseName.class,
    ...
    TestCaseName.class,
})
public class name {}
```

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# Test suite example

```
import org.junit.runner.*;
import org.junit.runners.*;

@RunWith(Suite.class)
@Suite.SuiteClasses({
    WeekdayTest.class,
    TimeTest.class,
    CourseTest.class,
    ScheduleTest.class,
    CourseComparatorsTest.class
})
public class HW2Tests {}
```

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# JUnit summary

- Tests need failure atomicity  (ability to know exactly what failed).
  - Each test should have a clear, long, descriptive name.
  - Assertions should always have clear messages to know what failed.
  - Write many small tests, not one big test.
    - Each test should have roughly just 1 assertion at its end.

- Always use a timeout parameter to every test.
- Test for expected errors / exceptions.
- Choose a descriptive assert method, not always assertTrue.
- Choose representative test cases from equivalent input classes.
- Avoid complex logic in test methods if possible.
- Use helpers, @Before to reduce redundancy between tests.