CSE 331

Unit Testing with 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).

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.

Unit testing

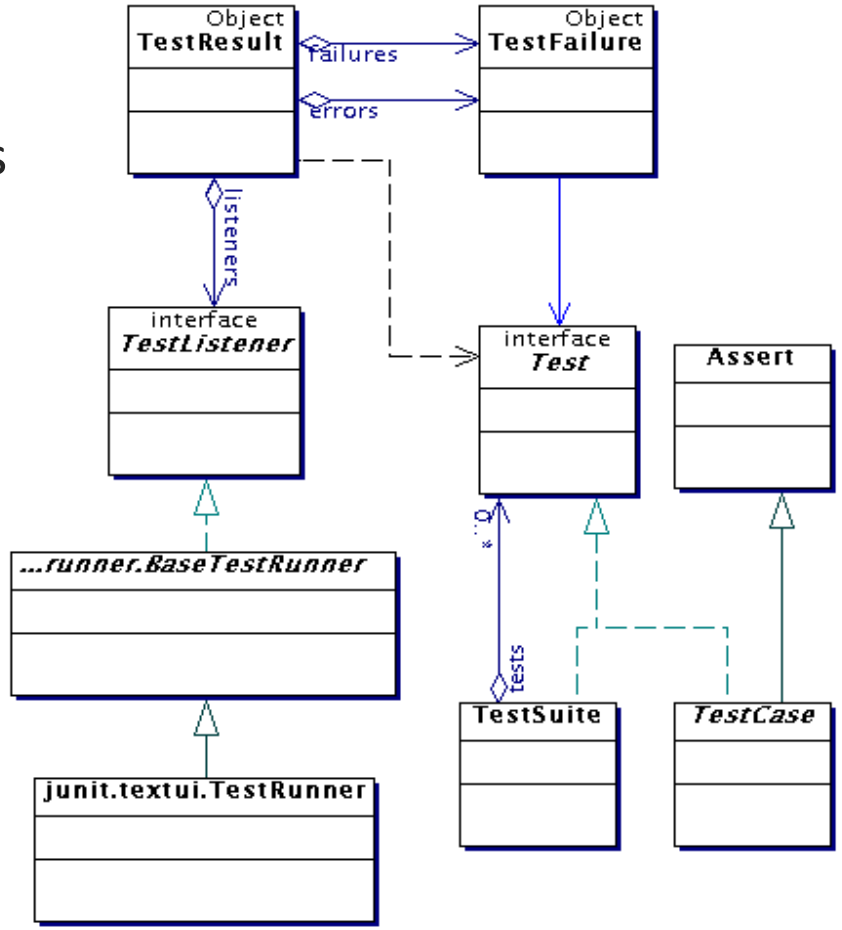
- **unit testing**: Looking for errors in a subsystem in isolation.
  - Generally a "subsystem" means a particular class or object.
  - The Java library **JUnit** helps us to easily perform unit testing.

- 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.

Architectural overview

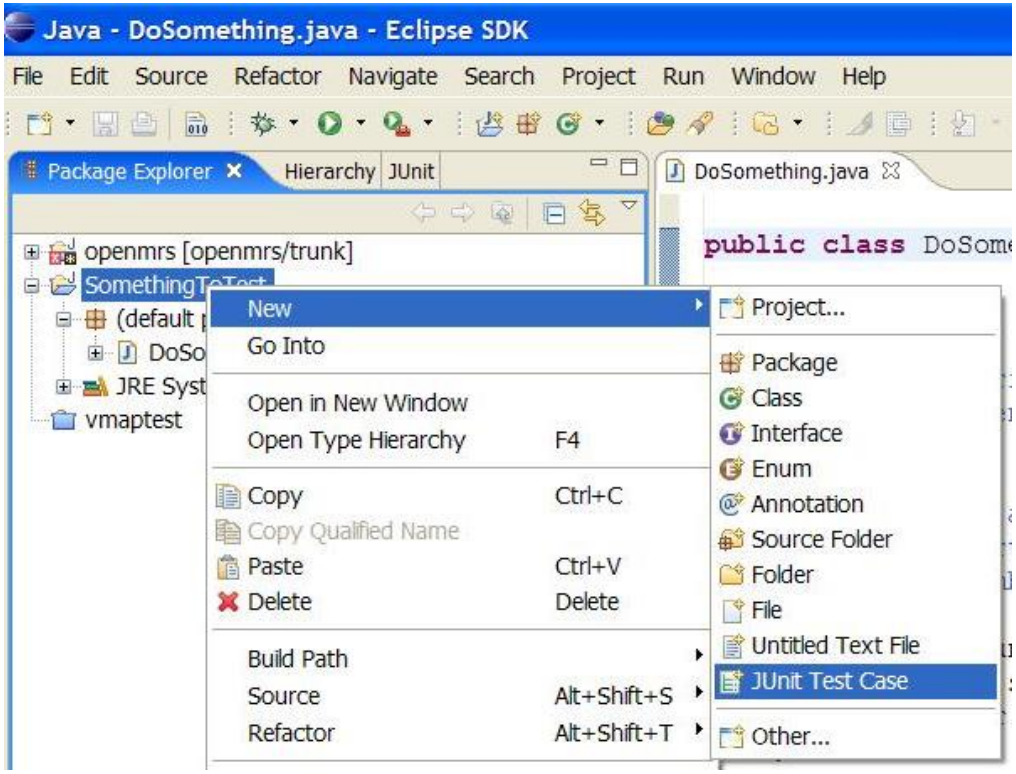
- JUnit test framework is a package of classes that lets you write tests for each method, then easily run those tests
- **TestRunner** runs tests and reports **TestResult**s
- You test your class by extending abstract class ***TestCase***
- To write test cases, you need to know and understand the **Assert** class



JUnit and Eclipse

- To add JUnit to an Eclipse project, click:
  - **Project → Properties → Build Path → Libraries → Add Library... → JUnit → JUnit 4 → Finish**

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



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.

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`**`)`

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());
    }
```

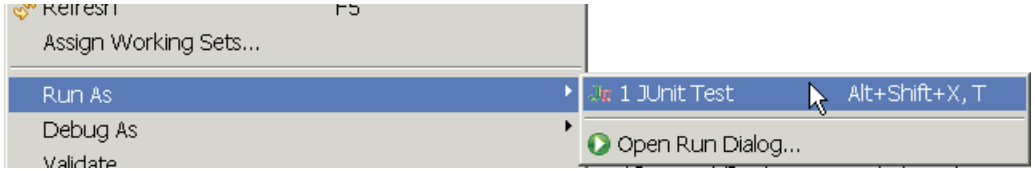
Running a test

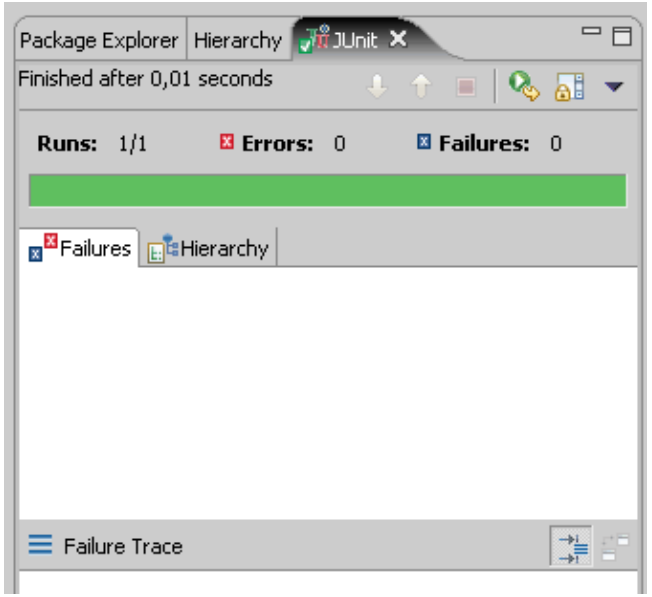
- Right click it in the Eclipse Package Explorer at left; choose:

  Run As → JUnit Test

- The JUnit bar will show **green** if all tests pass, **red** if any fail.

- The Failure Trace shows which tests failed, if any, and why.





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.

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);
    }
}
```

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
}
```

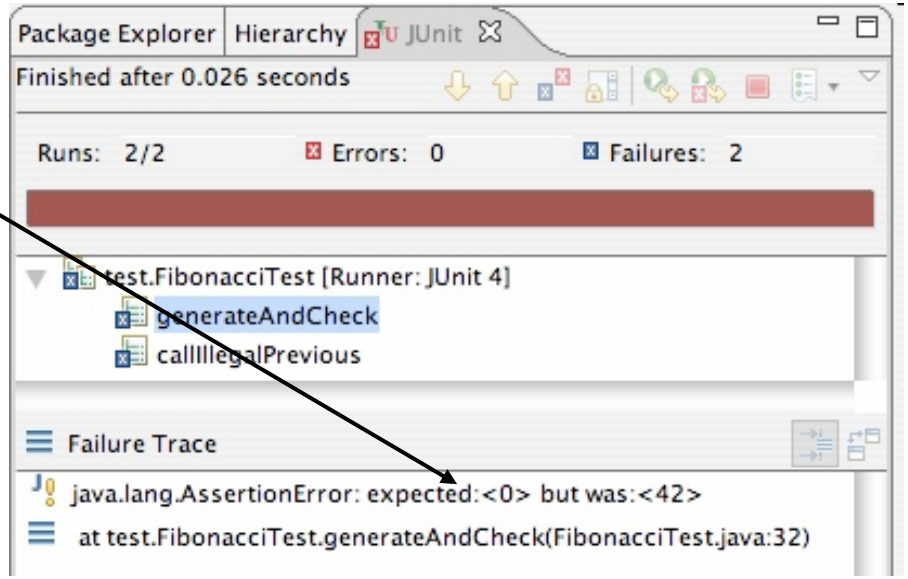
What's wrong with this?

```
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 got " + 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("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
```



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

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;
}
```

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
}
```

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

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

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
}
```

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.

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.

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(y1, m1, d1);
        act.addDays(add);
        Date exp = new Date(y2, m2, d2);
        assertEquals("after +" + add + " days", exp, act);
    }

    // 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(y1, m1, d1);
        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);
    }
```

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.

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.

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);
    }
    ...
}
```

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?)

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 {}
```

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 {}
```

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.

JUnit 4	Description
import org.junit.*	Import statement for using the following annotations.
@Test	Identifies a method as a test method.
@Before	Executed before each test. It is used to prepare the test environment (e.g., read input data, initialize the class).
@After	Executed after each test. It is used to cleanup the test environment (e.g., delete temporary data, restore defaults). It can also save memory by cleaning up expensive memory structures.
@BeforeClass	Executed once, before the start of all tests. It is used to perform time intensive activities, for example, to connect to a database. Methods marked with this annotation need to be defined as static to work with JUnit.
@AfterClass	Executed once, after all tests have been finished. It is used to perform clean-up activities, for example, to disconnect from a database. Methods annotated with this annotation need to be defined as static to work with JUnit.
@Ignore or @Ignore("Why disabled")	Marks that the test should be disabled. This is useful when the underlying code has been changed and the test case has not yet been adapted. Or if the execution time of this test is too long to be included. It is best practice to provide the optional description, why the test is disabled.
@Test (expected = Exception.class)	Fails if the method does not throw the named exception.
@Test(timeout=100)	Fails if the method takes longer than 100 milliseconds.