Software Design and Construction

159.251

Software Testing

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References

[CC] Robert Martin:
Clean Code: A Handbook of Agile Software Craftsmanship.
Prentice Hall 2009.

[EJ] Joshua Bloch:
Effective Java Second Edition.
Sun Micro 2008.

Additional Readings

Kent Beck, Erich Gamma: The JUnit Cookbook
http://junit.sourceforge.net/doc/cookbook/cookbook.htm

Robert Martin: The Three Rules of TDD
http://butunclebob.com/ArticleS.UncleBob.TheThreeRulesOfTdd

Summary

- the problem of program semantics
- assertions
- unit testing
- test-driven development
- testability as design goal
- black-box vs white-box testing
- mock testing
- boundary testing
- testing non-functional requirements
- user interface testing
- assessing test coverage
- end user testing

The Problem of Semantics

- ***semantics*** *- the meaning of a word, phrase, sentence, or text* (Oxford Dictionary)
- mainly applies to methods
- objects - entity with state, state is changed by methods

- **How can be describe what methods do?**
  - describe state change
  - describe state before, and state after method invocations
  - use pre- and postconditions

Example

```
public class Account {
      private int amount = 0;
      public void deposit(int sum) {
            ...
   }
      public void withdraw(int sum) {
            ...
   }
}
```

deposit sum, the amount should increase by sum, sum must be >0, otherwise an IllegalArgumentException is thrown

withdraw sum, the amount should decrease by sum, and sum must be less than the amount, otherwise an IllegalArgumentException is thrown

Semantics and Compiled Languages

- New programs sometimes have misconceptions about programs

  "if it compiles, it works!"
- based on the observation that compilers in languages with static types (like Java) will find and report many errors
- however, there are obvious limits to this

Compiler Limitations

```
public class Math {
        // add two numbers
        public String add(int i,int
j){
                return 42;
    }
}
```

the (Java) compiler will find this bug: the return type should be int, not string

```
public class Math {
        // add two numbers
        public int add(int i,int j) {
                return 42;
    }
}
```

for the compiler, this is **correct**! **BUT** wrong semantic!

```
public class Math {
        // add two numbers
        public int add(int i,int j) {
                return i+j;
    }
}
```

this is the intended version that has the correct **meaning** (=semantics)

Embedding Semantics in Code

- design by contract (DbC) proposed by Bertrand Meyer: add pre- and postconditions ("**expects**" and "**ensures**") directly to method declarations
- part of the Eiffel programming language
- allows verification: prove that a system is correct with respect to these constraints
- but:
  - not available in mainstream Java (although some extensions like JML and contract4j exist)
  - verification difficult and may impose runtime overhead
  - writing precise contracts can be difficult
- We covered this fully in 159272!

Java Assertions

- simple mechanism to add constraints to code
- syntax:
  - `assert condition`
  - `assert condition:message`
- condition must evaluate to a boolean (True or False)
- can be used to specify pre- and post conditions depending on where assertions are used within the method body
- but note that assertions might not always be on – for example, in case that precondition checks might be missed !!

Java Assertions ctd

- by default, assertions are **not** checked at runtime
- they must be explicitly enabled by starting the JVM with the parameter `-ea`
- fine-grained switching is also supported (per package)
- if an assertion is violated (i.e., the condition evaluates to false), an AssertionError is thrown
- for more info, see:
  - http://docs.oracle.com/javase/1.4.2/docs/guide/lang/assert.html
  - http://www.deitel.com/articles/java_tutorials/20060106/Assertions.html

Example: Accounts with Asserts

```
public class Account {
        private int TotalAmount = 0;
        public void deposit(int amountToAdd) {
                assert amountToAdd > 0;
                int oldAmount = this.amountToAdd;
                ...
                assert amount > amountToAdd;

                assert amount == oldAmount + amountToAdd;
    }
        public void withdraw(int sum) {
                ...
    }
}
```

precondition

postcondition 1 (coarse)

postcondition 2 (better)

Contract Patterns and APIs

- conditional runtime exceptions to check preconditions

```
if (sum<0) throw new IllegalArgumentException(..)
```

- contract APIs wrapping conditional preconditions:
  - com.google.common.base.Preconditions
  - org.apache.commons.lang3.Validate
- contract annotations (JSR303/349):
  - javax.validation.constraints @Max, @Min, NotNull, ..
- checkerframework (annotations with static checks)

Tests as Interpolation Semantics

- it is hard to specify and prove correctness for all possible objects and values
- but what about if we can prove correctness for selected objects and values
- example:
  - amount of account is 100, deposit 10, results should be 110
  - amount of account is 0, deposit 42, results should be 42
  - amount of account is 100, deposit -10, result should still be 100, and an IllegalArgumentException is thrown

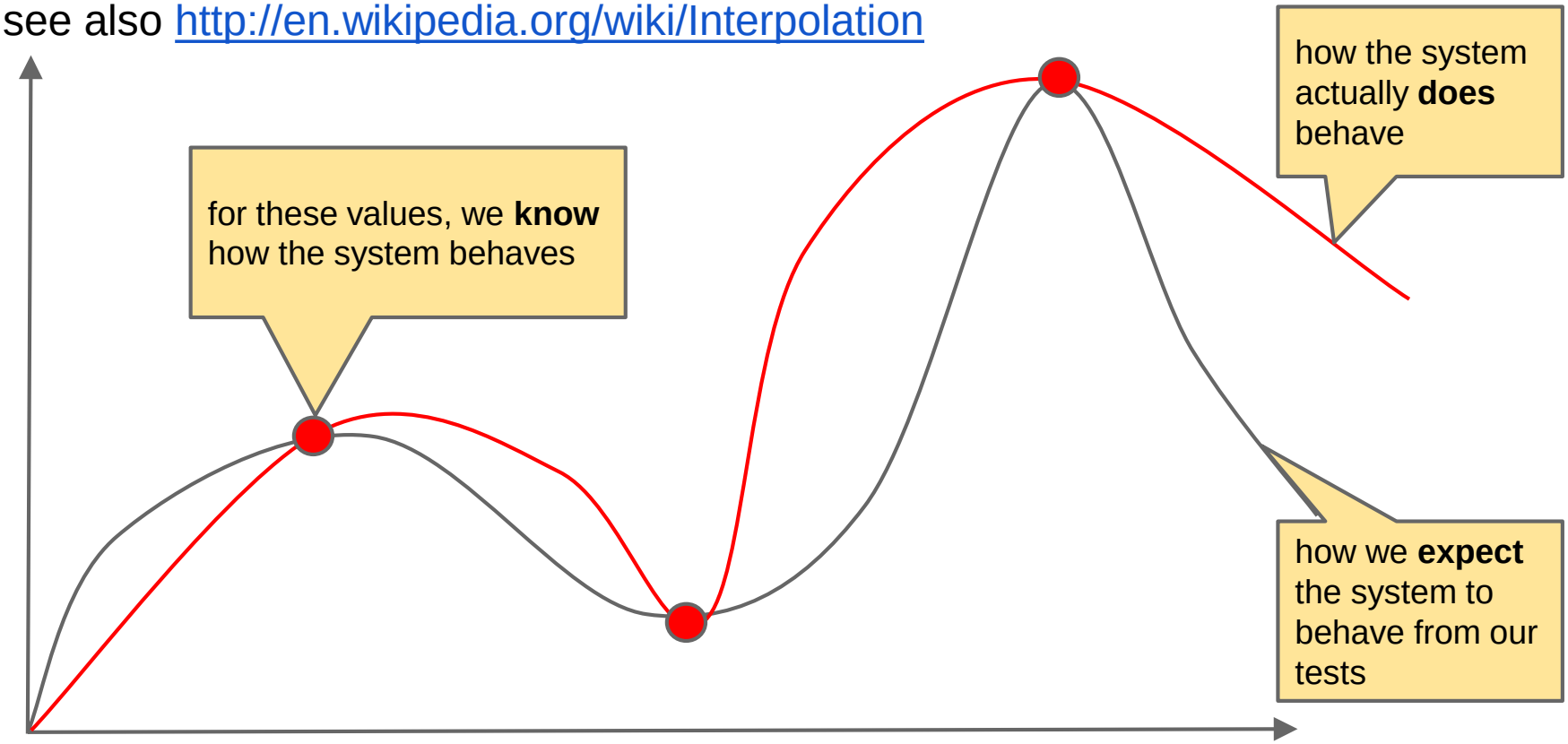
- then **infer** that this will work for other values as well!
- our test cases **do not prove** that the system behaves correctly, but they can provide a (potentially sufficient) approximation of correctness

The Interpolation Metaphor

Interpolation *(Mathematics): insert (an intermediate value or term) into a series by estimating or calculating it from surrounding known values.*

Oxford Dictionary.

see also http://en.wikipedia.org/wiki/Interpolation



Challenges

- is there a mechanism to write (a lot of) **inexpensive** tests to get many points for interpolation?
- are some test cases **better** than others to interpolate?
- how can we **recalibrate** tests if we find that our approximation is not sufficient?

Consequences

- **test cases cannot prove correctness (the absence of bugs, compliance to specification)**
- the code that is being tested may not contain a bug, or the parameters used in the tests do not show the bug
- but test cases can prove **incorrectness**: the **presence of bugs**
- therefore, **a good test is a test that fails**

Sourcing Tests

- tests from **requirements**: describe what user wants (e.g., example calculations)
- tests from **bug reports**: describe why/how the system fails
- tests serve two purposes:
  - **validation** - did we built the right system?
  - **verification** - did we built the system right?
- tests from requirements contribute more to validation
- tests from bug reports contribute more to verification

Testing Level

- **Unit testing:** test the smallest units in the software (classes, functions etc.)
- **Integration testing:** test multiple units together (multiple classes or separate functionalities)
- **System testing:** test the whole system together

Writing Tests: JUnit

- JUnit is a popular library to write (unit) tests for Java
- developed by Kent Beck and Erich Gamma
- derived from SUnit for Smalltalk (also by Beck/Gamma) in the late 90ties
- integrations: IDEs(Eclipse), ANT, command line
- current version (annotation based): 4.* - major differences to 3.* !
- clones: various "X"Units exist for other languages (NUnit, PUnit, ...)
- Alternatives for Java: TestNG

JUnit 4 Basics

- tests are public methods in a test class annotated with **`@org.junit.Test`**
- Test classes are the same as normal classes! test classes are not special in any other way: they don't have to subclass/implement a particular superclass/interface

- this makes it possible to add test methods to any class
- tests check conditions that express expectations
- this is done through static methods `org.junit.Assert.assert*` that are usually imported using static imports (i.e., that they can be used like functions within the test classes)

JUnit Asserts

- asserts accept a message parameter - this will be used when assertion fails
- basic asserts:
  - `assertTrue`, `assertFalse`
  - `assertNull`, `assertNotNull`
- comparisons:
  - `assertEquals` - compares expected with computed value using `equals()`
  - `assertEquals` also works for primitives, for numerical datatypes a delta can also be used (difference between expected and actual is < delta)
  - `assertSame` - compares expected with computed value using ==

Test Oracles

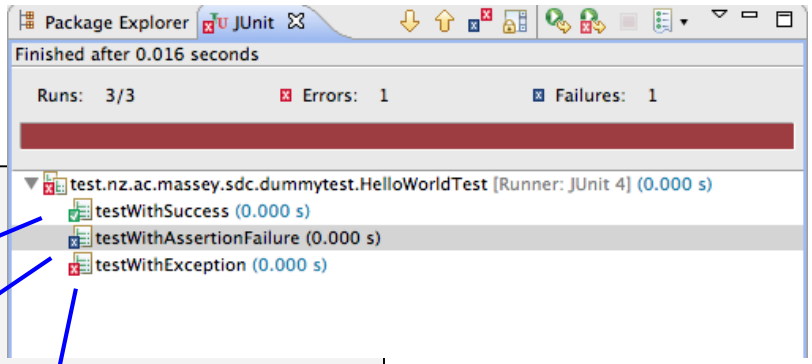
- assertEquals/ assertSame compare **expected** with **actual** values
- the expected values are also called **test oracles**
- oracle refers to the expected state of the system at the end of a test

JUnit Failing Tests

- if an assertion fails, an assertion error is generated
- JUnit catches this error, and marks the test as **failed**
- tests can also fail for another reason: if the execution of tests throws an exception
- JUnit runners are front ends for JUnits - user interfaces used to control and execute test
- example: graphical JUnit runners such as the Eclipse JUnit runner (an Eclipse view)
- graphical JUnit runners will visualise this differently, usually using colour codes:
  - green - test succeeds
  - gray - test fails due to `AssertionError`
  - red - tests fails due to `exception`

Example: Possible Test Outcomes

```
public class HelloWorldTest {
        @Test
    public void testWithSuccess() {
                assertTrue(true);
        }
        @Test
    public void testWithAssertionFailure() {
                assertTrue(false);
        }
        @Test
    public void testWithException() throws Exception {
                throw new java.io.IOException();
        }
}
```



JUnit runner in Eclipse

test methods can declare exceptions!

Test Fixtures

photo from
http://theinspirationroom.com/daily/print/2008/10/mercedes_crash_test_mammogram.jpg

- Know as “Test setup”
- prepare: standardised environment: make tests repeatable and predictable
- tests should run in separation (should not interfere with each other)
- clean up after the test to restore environment

Test Fixtures

- run a method before each test to prepare test:
  - annotated with `@org.junit.Before`
  - this is used to initialise the objects to be tested
- run a method after each test to clean up:
  - annotated with `@org.junit.After`
  - this is used to release/reset objects to be tested
- advanced:
  - static methods annotated with `@org.junit.BeforeClass` and `@org.junit.AfterClass`
  - these methods are executed once before/after the entire set of tests execute
  - these methods are mainly used for optimisation, and should be used with caution

Case Study: Testing Tax Calculator

- algorithm: NZ uses a progressive tax system with tax brackets
- the parameters used are from 2012, see http://www.ird.govt.nz/how-to/taxrates-codes/itaxsalaryandwage-incometaxrates.html for details and examples
- assume we have to develop a tax calculator
- requirements: should implement the algorithm described on the IRD web site
- source code: https://bitbucket.org/jensdietrich/oop-examples/src/1.0/junit-primer/

Tax Calculator Implementation

```
public class IncomeTaxCalculator {
        double[] brackets = {0,14000,48000,70000};
        double[] taxRates = {10.5,17.5,30,33};
        public double calculateIncomeTax(double income) {
        if (income<0) throw new IllegalArgumentException();
                double tax = 0.0;
                for (int i=brackets.length-1;i>=0;i--) {
                double bracket = brackets[i];
                double taxRate = taxRates[i];
                if (income>bracket) {
                        double taxableInThisBracket = income-bracket;
                        income = income - taxableInThisBracket;
                        tax = tax + taxableInThisBracket*taxRate/100;
                }
                }
                return tax;
    }
}
```

Tests

```
import org.junit.*;

public class IncomeTaxCalculatorTests {

	private IncomeTaxCalculator calculator = null;

	@Before
	public void setup() {
		calculator = new IncomeTaxCalculator();
	}
	@After
	public void tearDown() {
		calculator = null;
	}
```

import annotations: **@Before**, **@After**, **@Test** etc

set up test environment **before** each test is executed

clean up test environment **after** each test has been executed

Tests (ctd)

```
import static org.junit.Assert.*;
...
	@Test
	public void test1() {
		double tax =
calculator.calculateIncomeTax(65238);
		assertEquals(12591.40,tax,0.01);
	}

	@Test
	public void test2() {
		double tax =
calculator.calculateIncomeTax(45000);
		assertEquals(6895.0,tax,0.01);
	}
```

this will import the assert* methods used below

annotation from org.junit to mark this as a test

acceptable delta between expected and computed value is 0.01 (1c)

expected value

computed value

the actual test(s): calculate income for a given salary, and compare it with the expected outcome (data from IRD web site)

Questions

There is no method to compare two doubles without a delta..

```
@Deprecated
public static void assertEquals(double expected, double actual)
```

delta - the maximum delta between expected and actual for which both numbers are still considered equal.

Do you know why?

What is a good Test Case?

- test cases should be **simple** and **readable**
- test cases should replace semantic comments
- if test cases are complex, then it becomes more likely that the test cases themselves are incorrect!
- **avoid procedural logic** (conditionals, loops) in tests as much as possible
- test **one concept at a time**, write many small "atomic" test cases
- this will make it much easier to **diagnose** software - to spot what causes a test to fail
- prefer to have just **one assertion per test** (although this can be unproductive, e.g., when testing larger data structures) – avoid Assertion Roulette!

The One Assertion Rule

- can conflict with other principle such as DRY
- example: assume you have a Person class with surName and firstName properties, and a method setFullName
- the idea is that you set a full name string set is parsed, and then firstName and surName are set
- to test this, it would be practical to have two assertions (for the firstName and the surName), otherwise you need to copy the code before the assertion

Boundary Testing

- test extreme/boundary values are more likely to fail
- problems tend to be "at the edges"
- therefore, they are more valuable tests
- tax calculator:
  - test with very small income
  - test with zero income
  - test with very large income
  - test with negative value (should throw exception)

Boundary Testing Example

```
@Test
public void testZero() {
        double tax = calculator.calculateIncomeTax(0);
        assertEquals(0,tax,0.01);
}
@Test
public void testSmallIncome() {
        double tax = calculator.calculateIncomeTax(10);
        assertEquals(1.05,tax,0.01);
}
@Test
public void testLargeIncome() {
        double tax = calculator.calculateIncomeTax(Integer.MAX_VALUE);
        // should be very close to the max tax rate
        assertEquals(0.33*Integer.MAX_VALUE,tax,Integer.MAX_VALUE*0.001);
}
```

test with the largest integer number (32bit) that can be represented in Java

Testing Exceptions (naive)

```
@Test
public void testNegativeIncome1() {
        try {
                double tax = calculator.calculateIncomeTax(-42);
                assertTrue(false);
        }
        catch (IllegalArgumentException x) {
                assertTrue(true);
        }
}
```

test fails if exception is **not** thrown

test succeeds if exception is thrown

Testing Exceptions (better)

```
@Test(expected=IllegalArgumentException.class)
        public void testNegativeIncome2() {
                calculator.calculateIncomeTax(-42);
        }
```

declare that the expected outcome is the exception

- JUnit 4 has built-in support for testing expected exceptions
- this is a good example how annotations are used for a declarative programming style (declare **what** to do, **not how** to do it)

Testing Non-Functional Properties

- aka "testing ilities"
- in general this is not straightforward, and relies on APIs to build assertions
- however, support for measuring runtime is built into JUnit
- use case: requirement that the tax calculator should calculate tax in <100ms
- use timeout property in test annotation!
- if tests timeout, they will **fail**!
- related:
    - **Stress tests** - test software with large data or transaction volumes to assess its **scalability** and **robustness** (fault tolerance)
    - **Smoke tests** - ensuring that the most important functions work correctly .

Tests with Timeouts

```
@Test(timeout=100)
public void test1InclPerformance() {
        double tax = calculator.calculateIncomeTa
        assertEquals(12591.40,tax,0.01);
}

@Test(timeout=100)
public void test2InclPerformance() {
        double tax = calculator.calculateIncomeTax(45000);
        assertEquals(6895.0,tax,0.01);
}
```

declare that the expected outcome is the exception

- to “test the tests”, the calculation must be delayed
- this can be done by adding `Thread.sleep(1000)` to the `calculateIncome` method - this will cause the method execution to pause for 1s

Parameterised Tests

- often, many tests have the same structure, and only use different values (as parameters or expected values)
- sometimes, clients supply test data as data files (e.g., spreadsheets)
- writing individual tests is expensive, and may lead to copy and paste
- JUnit offers parameterised tests as a solution (and to make your tests DRY ..)
- the idea is to **inject parameters** into tests using the constructor of the test class
- the parameters are supplied by a feeder method
- a special test runner will read the feeder method, and instantiate the test class for each data record supplied

Parameterised Tests Example

```
@RunWith(value = Parameterized.class)
public class IncomeTaxCalculatorBatchTests {
        private IncomeTaxCalculator calculator = null;
        private double income = 0.0;
        private double expectedIncomeTax = 0.0;
        public IncomeTaxCalculatorBatchTests(double income, double expectedIncomeTax) {
                super();
                this.income = income;
                this.expectedIncomeTax = expectedIncomeTax;
        }
        @Parameters
        public static Collection<Object[]> data() {
                Object[][] data = new Object[][] {  { 0,0}, { 10000,1050.0 } ,{ 20000,2520.0 } , ...};
                return Arrays.asList(data);
         }
        @Test
        public void test() {
                double tax = calculator.calculateIncomeTax(this.income);
                assertEquals(this.expectedIncomeTax,tax,0.01);
        } ...
```

use a special test runner that can bind parameters

this is the constructor used to inject parameters

the **feeder** method: each element is an array of data that instantiates a test. The **order** and **types** must match the parameters in the constructor!

in the actual test method, the parameters can now be simply referenced as instance variables

User Interface Testing

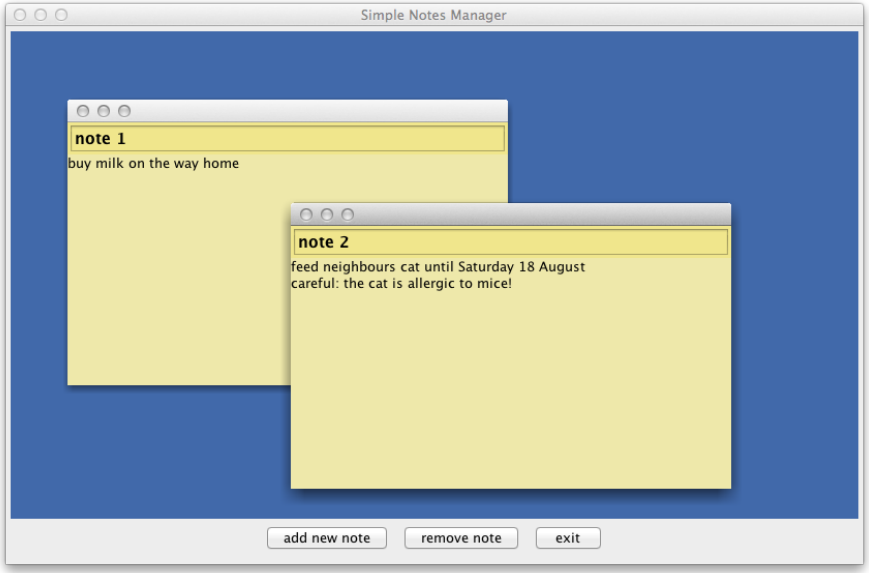
- (junit) testing can be extended to test user interaction
- frameworks like abbot can script and replay user interactions, and define asserts based on the state of user interface components
- popular package to test web user interfaces: selenium
- low level support for UI testing: java.awt.Robot
- this class allows to programmatically simulate a user interaction with IO hardware (keyboard, mouse)

User Interface Testing (ctd)

- while UI testing is possible, it is often better to focus more on testing other parts of the application
- UI testing is sometimes useful for **acceptance testing**: UI tests replay end user (client) interaction
- acceptance testing is part of validation (did we build the right system)

For your knowledge Only – not in exam

Case Study: The Note Manager



- simple ui, designed with UI builder
- uses multi-document interface MDI - (windows within window)
- users can add and remove notes
- users can edit title and content (body) of each note
- source: https://bitbucket.org/jensdietrich/oop-examples/src/1.0/gui-test/

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UI Test: Fixture

```
public class TestNoteManager {
	private NotesManager ui = null;
	private Robot robot = null;
	@Before
	public void openNoteManager() throws Exception {
		ui = new NotesManager();
		ui.setVisible(true);
		robot = new Robot();
	}
	@After
	public void waitABit() throws Exception {
		robot = null;
		Thread.sleep(1000);
	}
```

this will open the application (the window will pop up)

create a new robot to simulate user input

wait 1 s - this is for us to better see what is going on, otherwise windows close too quickly

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UI Test: Test Adding Notes

```
@Test
public void testAddOne() throws Exception {
	JButton btnAdd = ui.getBtnAddNote();
	btnAdd.doClick();
	assertEquals(1,ui.getNoteEditors().length);
}

@Test
public void testAddTwo() throws Excepti
	JButton btnAdd = ui.getBtnAddNot
	btnAdd.doClick();
	btnAdd.doClick();
	assertEquals(2,ui.getNoteEditors().length);
}
```

note that the NotesManager has to expose components with getters just to make them testable!

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UI Test: Editing Notes

```
@Test
public void testAddAndEditTitle() throws Exception {
        JButton btnAdd = ui.getBtnAddNote();
        btnAdd.doClick();
        Thread.sleep(1000);
        NoteEditor editor = ui.getNoteEditors()[0];
        JTextField titleEditor = editor.getTitleEditor();
        clickOn(titleEditor);
        enterString("Hello world");

        // wait to give event delivery some ...
        Thread.sleep(1000);
        Note note = editor.getModel();
        assertEquals("Hello world",note.getTitle());
}
```

uses some utilities to simulate input

wait to give event delivery some time!

the assert checks the model edited by the UI application

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UI Test: Using Robot

```
private Robot robot = null;
..
private void moveMouseTo(Component component) {
        Point p = component.getLocationOnScreen();
        robot.mouseMove(p.x+10, p.y+10);
}

private void clickOn(Component component) {
        component.requestFocus();
        robot.mousePress(InputEvent.BUTTON1_MASK);
}
```

move mouse programmatically

click mouse programmatically

WhiteBox vs BlackBox Testing

- blackbox testing: testing at the interfaces of software, internal structure is not revealed or unknown
- whitebox testing: testing using knowledge about the internals of the software system

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Case Study: Testing Web Applications

- a Java web application is written using J2EE - the Java enterprise API
- a simple way to do this is to write a servlet: a simple java class that produces responses (usually web pages) for (http) requests coming from web browser sessions
- Java web apps are packages as .. webapps
- web apps are then deployed within a J2EE compliant server
- there are several servers available, including Tomcat, Jetty, Glassfish and WebSphere
- the servers will route network requests to the servlets registered to handle them based on the address (URL) of the request

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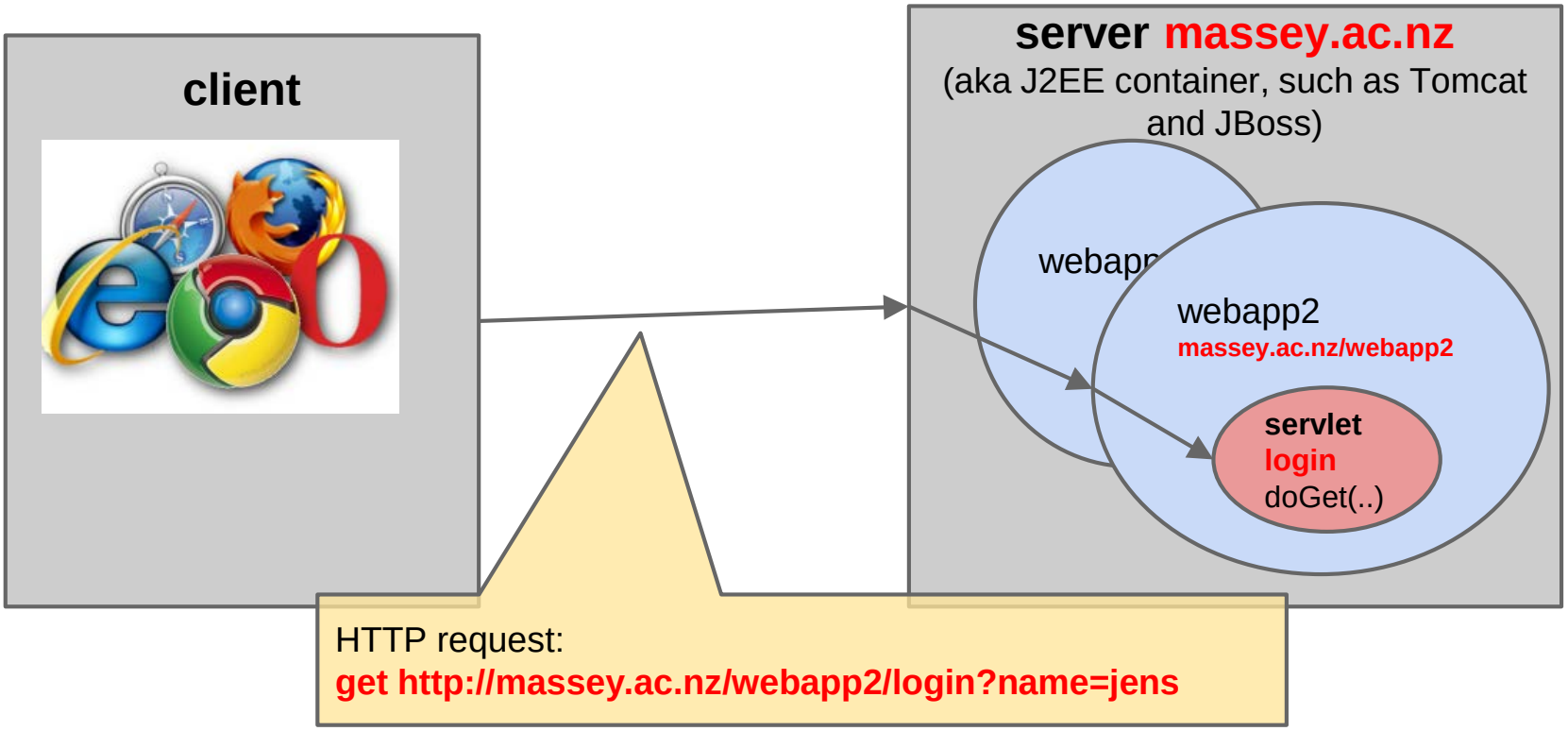
A J2EE Web Application



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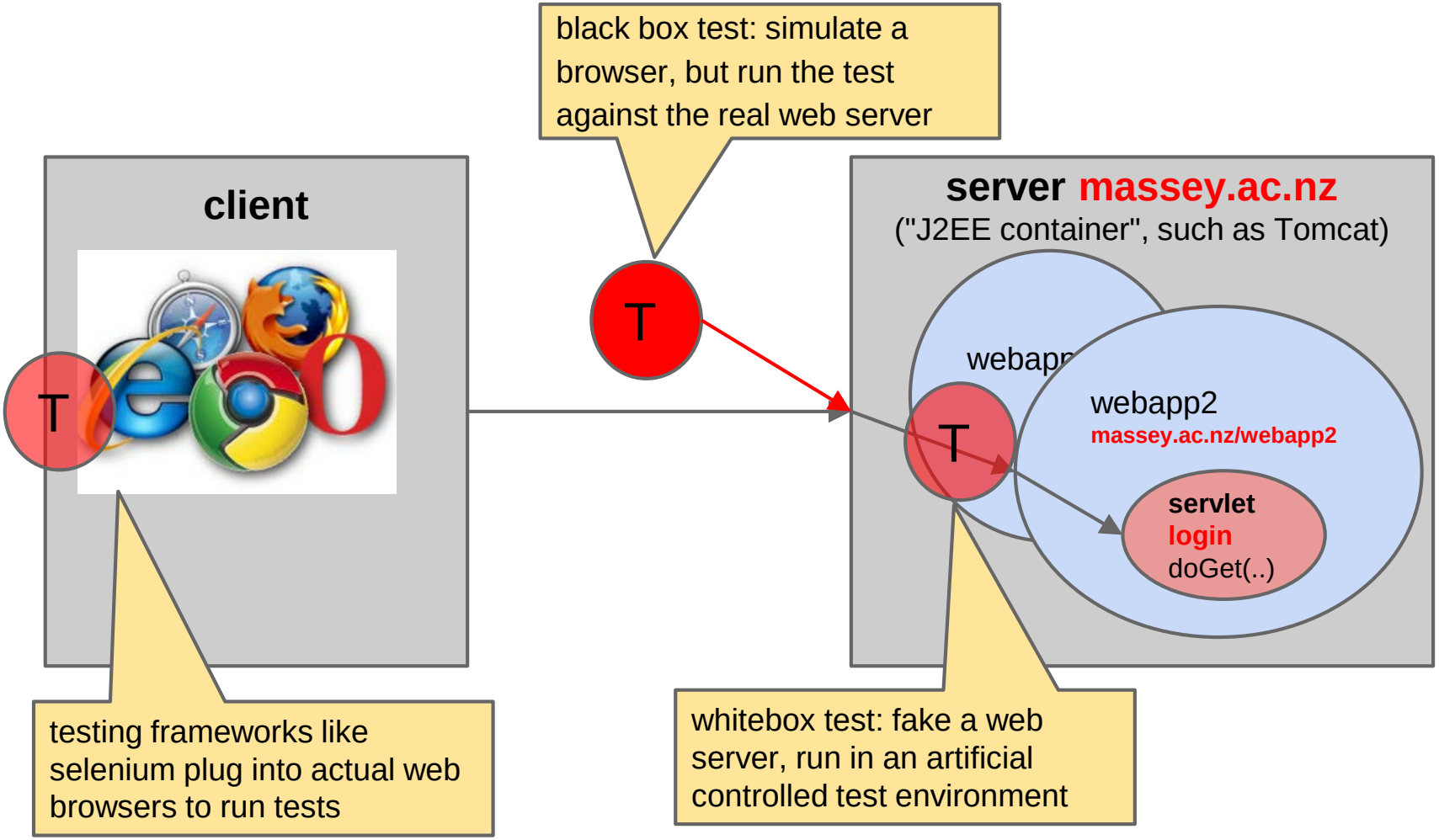
Where to Test



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Does you search engine know the answer?

- set up a **black box test** to figure out whether your search knows "the answer to life the universe and everything"
- we expect to find "The answer to life the universe and everything = 42" in the response page
- we need a networking API to run the test
- basic networking API: java.net.URL
- better: Apache HTTP client

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Does you search engine know the answer?

- challenge: testing from behind a proxy
- simple solution: set flag USE_PROXY in test class
- source: https://bitbucket.org/jensdietrich/oop-examples/src/1.0/blackbox-test/
  - this is a low level solution, libraries like JWebUnit should be used for production

- The example above uses Google, you can change the search into another browser such as Baidu or Bing or

Does you search engine know the answer? (ctd)

```
@Test(timeout=5000)
public void testFormSubmission() throws Exception {
    URIBuilder builder = new URIBuilder();

        builder.setScheme("http").setHost("www.google.com").setPath("/search
")
            .setParameter("q", "the answer to life the universe and
everything");
        URI uri = builder.build();

        HttpGet request = new HttpGet(uri);
        HttpResponse response = httpClient.execute(request);

        String content = EntityUtils.toString(response.getEntity());
        String expected = "The answer to life the universe and everything =
42";
        assertTrue(content.indexOf("expected)>-1);
}
```

use utilities to build a google query URL

execute query

result web site as one string

check whether the expected answer is returned

Blackbox Tests

- advantage: test against a real server
- disadvantage:

  expensive to setup tests to run against different servers –
  - requires server setup and maintenance
  - difficult to test part of the application in isolation
  - web site as string is too coarse for good tests, real-world web testing frameworks parse the page into a document object model (DOM), and provide a rich DOM-API to build assertions

Whitebox Test

- test server "from the inside"
- instead of running the web app deployed inside a real server, fake a server
- the contract between servlets and server mainly consists of abstract types defined in the J2EE specification
- a server has to implement these types, and multiple servers do this
- by definition, everything that implements those abstract types correctly is a server
- idea: build a fake server just for testing
- this approach is called **Mock Testing**, and is easy and inexpensive

Assumptions

- assertions represent **postconditions** - they are used to check the state of objects after some methods were invoked
- what about **preconditions?** - conditions that must be true for the test to make sense
  - JUnit uses assumptions for this purpose, in particular the method **`Assume.assumeTrue(expression)`**, where the (boolean) expression expresses the prerequisite

Assumptions (ctd)

[assumptions are] a set of methods useful for stating assumptions about the conditions in which a test is meaningful. A failed assumption does not mean the code is broken, but that the test provides no useful information.

The default JUnit runner treats tests with failing assumptions as ignored.

from http://junit.sourceforge.net/javadoc/org/junit/Assume.html

Note: the Eclipse test runner will marks tests with failed assumptions as **passed**!

Assumptions Example

- scenario: you have a class `Foo` with implementations of `equals` and `hashCode` that are inconsistent
- write a test that shows that two objects are equal but have different hash codes
- i.e., this test case **should fail**
- remember: a good test is a test that fails
- such a test **proves** that `equals` and hashCode are inconsistent

Example ctd: Two Assertions

```
public class TestFoo {
    private Foo foo1 = null;
    private Foo foo2 = null;
    @Before
    public void setUp() {
        foo1 = ..;
        foo2 = ..;
    }
    @Test
    public void test() {
        assertEquals(foo1,foo2);
        assertEquals(foo1.hashCode(),foo2.hashCode());
    }
}
```

if the two objects are not equal, the test will fail with the first assertion - but this is not the intention of the test!

Example ctd:
One (Complex) Assertion

```
public class TestFoo {
    private Foo foo1 = null;
    private Foo foo2 = null;
    @Before
    public void setUp() {
        foo1 = ..;
        foo2 = ..;
    }
    @Test
    public void test() {
        assertTrue(
            foo1.equals(foo2) &&
            foo1.hashCode()!=foo2.hashCode();
        }
}
```

better: explicitly test for violations of the rule!

Example ctd:
One Assertion + one Assumption

```
public class TestFoo {
    private Foo foo1 = null;
    private Foo foo2 = null;
    @Before
    public void setUp() {
        foo1 = ..;
        foo2 = ..;
    }
    @Test
    public void test() {
        assumeThat(foo1.equals(foo2));
        assertEquals(foo1.hashCode(),foo2.hashCode());
    }
}
```

if the two objects are not equal, the assumption will fail and the test **will "be ignored"** - in Eclipse this means that the test will actually pass

Dealing with Failed Assumptions

- the Eclipse test runner marks tests with failed assumptions as passed (success)
- the logic behind this is as follows: a test can be seen as rule:
  "if precondition(s), then postcondition(s)", or:
  "if assumptions [are true], then assertions [must be true]"
- the definition of the implication is (classical propositional logic) is:
  A implies B := not A or B (see also http://goo.gl/WvsxU)
- i.e. such a rule is always true if the prerequisite (=the assumption) **is false**

Coverage

- how can we assess which code is tested?
- we need a tool to figure out which parts of the code are visited by tests
- solution: measure **test coverage**
  - which classes are tested?
  - which methods are tested?
  - which blocks / lines of code are tested?

Example

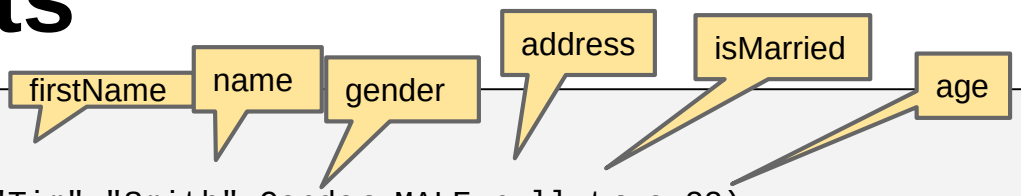
- POJO classes `Person`, `Address`
- `Person` has properties `firstName`, `name`, `age`, `gender`, `address`, and `isMarried`
- getters/setters, custom constructors, `equals` and `hashCode`
- custom method `getFullName()` in `Person`, prints salutation, first name and (last) name
- source: https://bitbucket.org/jensdietrich/oop-examples/src/1.0/coverage/

Example: Logic

```
public String getFullName () {
          String namePart = this.getFirstName() + " " +
this.getName();
          String salutationPart = null;
          if (gender==Gender.MALE) {
                    salutationPart = "Mr.";
          }
          else if (gender==Gender.FEMALE) {
                    if (this.isMarried) {
                              salutationPart = "Mrs.";
                    }
                    else if (age<19){
                              salutationPart = "Miss";
                    }
                    else {
                              salutationPart = "Ms.";
                    }
          }
          return salutationPart + " " + namePart;
}
```

fairly complex logic to implement english salutation rules based on gender, marital status and age

Example: Tests




```
@Test
public void test1() {
          Person p = new Person("Tim","Smith",Gender.MALE,null,true,22);
          assertEquals("Mr. Tim Smith",p.getFullName());
}

@Test
public void test2() {
          Person p = new Person("Kate","Smith",Gender.FEMALE,null,true,22);
          assertEquals("Mrs. Kate Smith",p.getFullName());
}

@Test
public void test3() {
          Person p = new Person("Kate","Smith",Gender.FEMALE,null,false,17);
          assertEquals("Miss Kate Smith",p.getFullName());
}
```

Problem: no test case for salutation **Ms**

Tooling: Emma

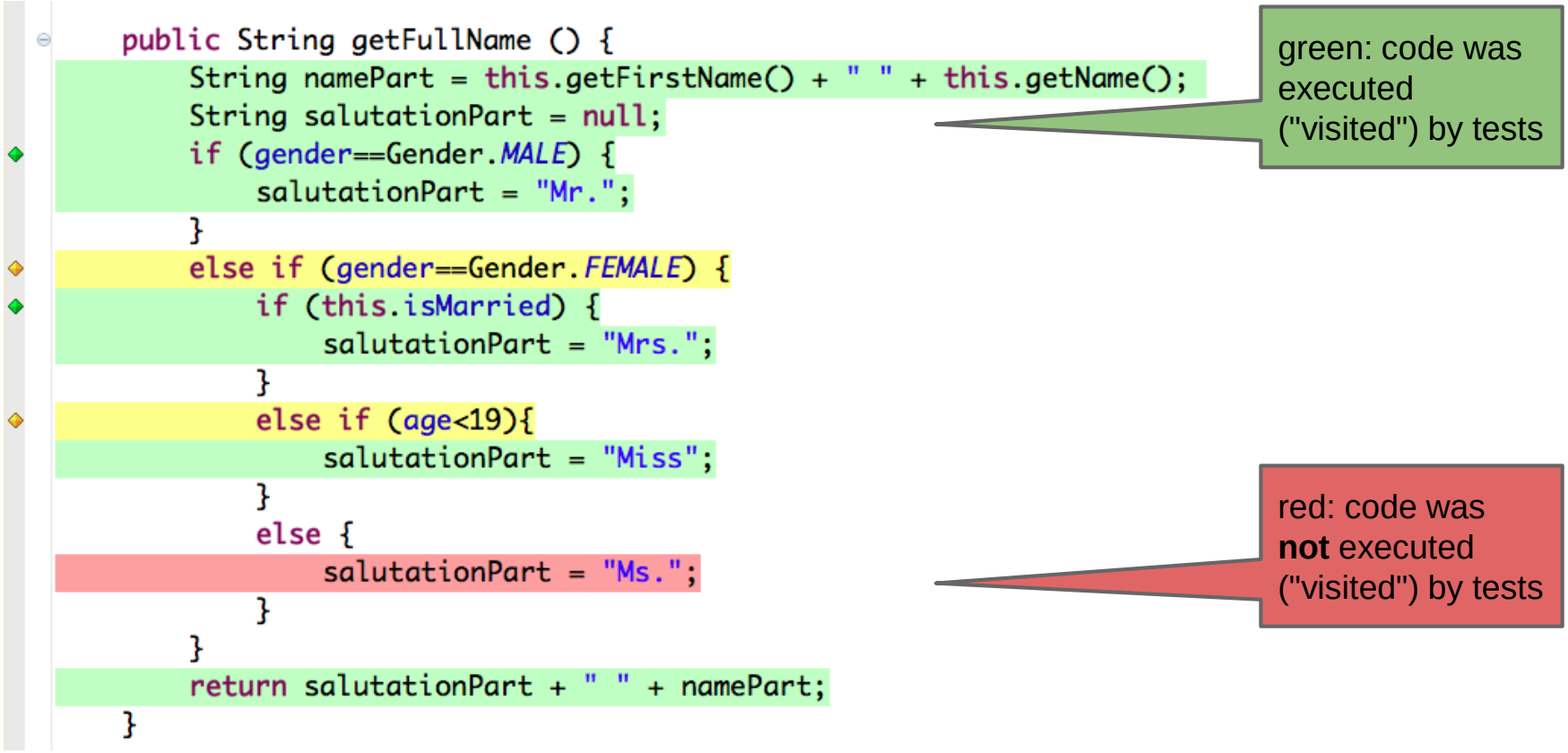
- there are several **test coverage tools**
- examples (Java): Clover, EclEmma, CodeCover,
- emma is good open source coverage tool:
  http://emma.sourceforge.net/
- integrations: Eclipse, ANT
- Eclipse & IntelliJ integration: EclEmma:
  http://www.eclemma.org/

Tooling: Emma (ctd)

- Emma supports the following coverage metrics: class, method, block, code
- using Emma in Eclipse**: right click on Project > Coverage As**
- Emma will then run all tests, register the executes methods, and highlight code that has been executed
- Emma can generate (html) reports
- generating reports in Eclipse:

  File > Export > Java > Coverage Report

Emma Annotations (in Eclipse)

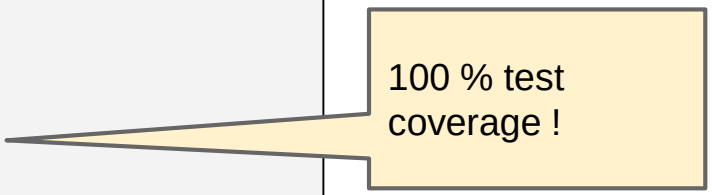


How Coverage Tools Work

- coverage tools manipulate (**instrument**) the program code (source or byte code)
- in each block or line, a method invocation (something like **emma.visited (aUniqueLabel)**) is added
- a database of all labels is created
- when the program runs (e.g., test cases are executed), some of the visited(label) methods are called - this "ticks off" labels in the database
- metrics are computed by comparing ticked off (visited) labels with unvisited labels
- Emma instruments byte code
- Java libraries exist that facilitate byte code instrumentation , e.g. Apache BCEL

High Coverage = Good Tests ?

```
public boolean isEven(int i) {
	if (i%2==0)
		return true;
	else
		return false;
}
…
@Test  public void test1() {
	isEven(2);
	assertTrue(true);
}
@Test  public void test2() {
	!isEven(1);
	assertTrue(true);
}
```



High Coverage = Good Tests ? ctd

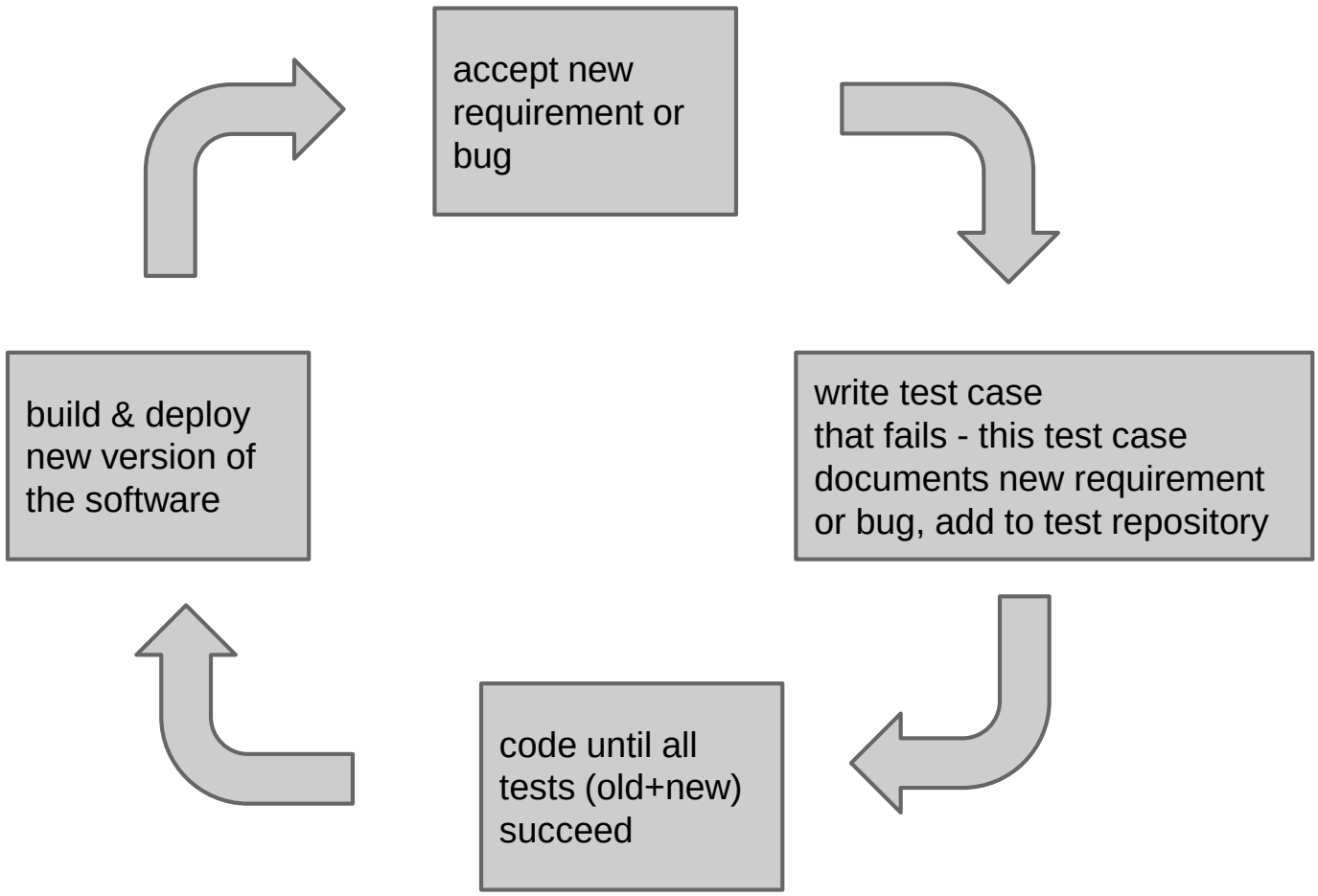
```
public boolean isEven(int i) {
      if (i%2==0)
            return true;
      else
            return false;
}
…
@Test  public void test1() {
      isEven(2);
      assertTrue(true);
}
@Test  public void test2() {
      !isEven(1);
      assertTrue(true);
}
```

but **poor assertions** - tests are almost meaningless *(they still test that no runtime exceptions occur ..)*

From Testing to Test-Driven Development (TDD)

- This was briefly covered in Lecture 2 (Agile)
- Important questions: **when to test?**
- in many traditional software (SDLC) , testing is done **after** the software has been written – this is called “test last”
- however, if test cases are seen as part of the specification, it makes sense to write them first
- this is called test-driven development (TDD)
- TDD is part of many modern "agile" methodologies, such as extreme programming

TDD


accept new requirement or bug
write test case that fails - this test case documents new requirement or bug, add to test repository
code until all tests (old+new) succeed
build & deploy new version of the software

How to Write Tests First

- write abstract types, and write tests against the abstract types
- use dummies
- write tests against classes and methods that do not yet exist (the tests will fail because they cannot be compiled!)

Example: Tests First - Step 1

```
public class IncomeTaxCalculator {
	public double calculateIncomeTax(double income) {
		return 42;
    }
}
```

- write minimal code, enough to support tests that can be compiled
- this code is not correct!
- this is the "use dummies" approach

Example: Tests First - Step 2

```
public class IncomeTaxCalculatorTests {
	private IncomeTaxCalculator calculator = null;
	@Before
	public void setup() {
		calculator = new IncomeTaxCalculator();
	}
	@Test
	public void test1() {
		double tax =
		calculator.calculateIncomeTax(65238);
		assertEquals(12591.40,tax,0.01);
	}
   ...
```

- write tests against the code from step 1
- tests can be compiled, but most will fail!

Example: Tests First - Step 3

```
public class IncomeTaxCalculator {
	double[] brackets = {0,14000,48000,70000};
	double[] taxRates = {10.5,17.5,30,33};
	public double calculateIncomeTax(double income) {
		if (income<0) throw new
IllegalArgumentException();
		double tax = 0.0;
		for (int i=brackets.length-1;i>=0;i--) {
			double bracket = brackets[i];
			...
```

- implement the tax calculator **until all tests succeed**
- then build and deploy

The Rules of TDD

by Robert Martin

1. You are not allowed to write any production code unless it is to make a failing unit test pass.
2. You are not allowed to write any more of a unit test than is sufficient to fail; and compilation failures are failures.
3. You are not allowed to write any more production code than is sufficient to pass the one failing unit test.

http://butunclebob.com/ArticleS.UncleBob.TheThreeRulesOfTdd

The Importance of Tests

- test cases are major assets produced in projects - they are **not second class citizens**
- they could be considered more valuable than the actual system - given the tests, a system could be easily re-implemented
- there is an ever-growing repository of tests - these tests re-calibrate our model of the software

The Importance of Tests (ctd)

- this is used for **regression testing**: uncover bugs caused by changes
- with automated tests, it is **inexpensive to test** - testing can be done often, and can even run in the background
- this facilitates **change**: it is now safe to change because **tests safeguard change**
- this makes testing a core principle of agile methodologies

Manual Tests

- there could still be some manual user tests, e.g. to assess the ergonomy of user interfaces
- these tests are expensive
- test protocols can be used to make tests **repeatable**
- in these test protocols, preconditions, the test fixture and the expected outcome are described
- manual tests are often used for acceptance testing by clients (validation testing)
- this is when clients decide whether to accept (and pay for) the system