Testing

Some slides adapted from FSE’98 Tutorial by Michal Young and Mauro Pezze’

• Execute program on sample input data
  – Check if output correct (acceptable)

• Goals
  – Increase confidence program works correctly
    • Acceptance Testing
  – Find bugs in program
    • Debug Testing
Simple Example

% java TestServlet HelloWorld /FooBar/Test > out

HTTP/1.0 200
Content-Type: text/plain

Hello /FooBar/Test

% diff out expectedOutput

Limitations of Testing

• Program runs on (very small) subset of input data
  – Exhaustive testing usually impossible
  • Too large input space (possibly infinite)
• Many situations hard to test
  – Parallel code (due to non-determinism)
  – Hard-to-reach states (e.g., error states)
  – Inadequate test environment (e.g., lack of hardware)
• Testing cannot prove absence of bugs
  – Especially a problem in security
Black Box Testing

- Pick subcomponent of program
  - Internals of component not considered
- Give it inputs
- Compare against expected outputs

But how do I know what the expected outputs are?
- Depends on the specification (more later…)
The Test Case Generation Problem

• How to choose tests that will show that my program works?
  – Must consider “operational scenarios”
    • What is legitimate input?
    • What is the correct action or output?
  – Must consider “abnormal behaviors” as well

• How can I make sure that all of the important behaviors of my program have been tested?
  – Usually, you can’t!

Test Cases via Specifications

// Return true if x in a, else returns false
boolean contains(int[] a, int x);

• Two “paths” in specification
  – Test case where x is in a
  – Test case where x is not in a
Test Cases via Inferred Implementation

• Think about how the implementation might look
  – Test by boundary condition
    • What test cases are likely to exercise the same logic?
    • Want to avoid redundant tests, to save time
  – Test by common mistake
    • What cases may be tricky to implement?
• At the same time, tests should still be implementation-independent

Test Cases via Boundary Conditions

```java
interface List { ...  
  Inserts the specified element at the specified position in this list (optional operation). Shifts the element currently at that position (if any) and any subsequent elements to the right (adds one to their indices).
  
  public void add(int index, Object element)
}
```

• Test with empty list
• Test with index at first/last element
• Others?
Test Cases via Common Mistakes

// Appends l2 to the end of l1
void append(List l1, List l2);

• Does append work if l1==l2?

```java
class A {
    ...boolean equals(...);
}
```

• Does equals work if operand is an Object?

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White/Glass Box Testing

• Pick subcomponent of program
• Give it inputs
  – Based on component code
    • If you don’t execute the code, you don’t know whether or not it works
• Compare against correct outputs (properties)
Statement Coverage

One test case \(n=1, a[0]=-7, x=9\) covers all statements.

Faults handling positive values of \(a[i]\) not revealed.

Branch Coverage

Must add test case \(n=1, a[0]=7, x=9\) to cover false branch of if.

Faults handling positive values of \(a[i]\) revealed.
Faults exiting the loop with \(a[i] < x\) not revealed.
Condition Coverage

```c
int select(int[] a, int n, int x) {
    int i=0;
    while (i<n && a[i] < x) {
        if (a[i]<0)
            a[i] = - a[i];
        i++;
    }
    return 1;
}
```

Both i<n and a[i]<x must be false and true for different tests. Must add tests that cause loop to exit for a value greater than X. Faults that arise after several loop iterations not revealed.

Structural Coverage Testing

- Adequacy criteria
  - If significant parts of program structure are not tested, testing is surely inadequate
- Control flow coverage criteria
  - Statement (node, basic block) coverage
  - Branch (edge) coverage
  - Condition coverage
- Attempted compromise between the impossible and the inadequate
Granularity of Tests

- **Unit testing**
  - Individual components of a program are tested
    - Methods
    - Classes/packages
    - Processes of a distributed system
- **Integration testing**
  - Test case inputs to subsystem, multiple subsystems, or the whole program, and outputs examined

White/Glass Box vs. Black Box

- **Black box**
  - depends on spec
  - scales up
    - different techniques at different granularity levels
  - cannot reveal code coverage problems
    - same specification implemented with different modules
- **White box**
  - depends on control or data flow coverage
  - does not scale up
    - mostly applicable at unit and integration testing level
  - cannot reveal missing path errors
    - part of the specification that is not implemented
Testing Activities

- Test case execution is only a part of the process
- Must also consider
  - Test case generation
  - Test result evaluation
- Planning is essential
  - To achieve early and continuous visibility
  - To choose appropriate techniques at each stage
  - To build a testable product
  - To coordinate complementary analysis and testing

The Testing Environment

- Want to create a scaffold for executing tests
  - Code infrastructure to run tests and check output
- Many benefits
  - Can automate testing process
  - Useful for regression testing
- But, can take some time to implement
Testing Environment Components

- A user to generate input for tested component
- An oracle for verifying the results are correct
- These two may be combined into a single system

Unit Testing with Junit

- Testing environment for writing black-box tests
  - Write special TestCase classes to test other classes
  - Several ways to use/set up test cases
- Can be downloaded from
  - http://www.junit.org
JUnit Philosophy

• Iterative, incremental process
  – Write small black-box test cases (as needed)
  – Test-as-you-go
    • I.e., after changes, when new method added, when bug identified
• Junit test cases must be completely automated
  – No human judgment
  – Easy to run many of them at the same time
• Goal: lots of bang for the buck
  – Even simple tests can find many bugs quickly

TestCase Example with Lists

```java
import junit.framework.*;
import java.util.*;

public class ListTest extends TestCase {
    public void testAdd() {
        LinkedList l = new LinkedList();
        Object o = new Object();
        l.add(o);
        assertTrue(l.contains(o));
    }

    public void testIsEmpty() {
        LinkedList l = new LinkedList();
        assertTrue(l.isEmpty());
    }
}
```

Create objects
Perform test/check result
Another test
To Execute Tests within a Class

• Pick a Test Runner:
  – junit.awtui.TestRunner – Graphical
  – junit.swingui.TestRunner – Graphical
  – junit.textui.TestRunner – Textual

• Invoke on the test case class
  > java junit.textui.TestRunner ListTest
     ..
  Time: 0.03
  OK (2 tests)

JUnit Components

• Test cases (class TestCase)
  – Individual tests
  – Can reuse test case setup (optional)
• Test suites (class TestSuite, not used in Eclipse)
  – Test case container
• Test runner (various classes)
  – Executes test suites and presents results
  – Can also execute tests within Eclipse
Each Test Has Three Parts

• Code that creates test objects
  – Create a subclass of \texttt{junit.framework.TestCase}

• Code that executes the test
  – Override the method \texttt{runTest()} (which executes the test)

• Code that verifies the result
  – E.g., use \texttt{junit.framework.assertTrue()} to check results (throws exception is test fails)

Setup/Teardown

• Creating objects for each test insufficient
  – Setup overhead grows as number of tests grows
  – Instead, group setup (and teardown) code in one place and reuse

• \texttt{junit.framework.TestCase.run()} executes test case:
  – public void \texttt{run()} { \texttt{setUp(); runTest(); tearDown();} }
  \hfill • Do not override this method!
  – Put setup code in \texttt{setUp()} method
  – Put cleanup code in \texttt{tearDown()} method
public class ListTest extends TestCase {
    private Object o;
    public void setUp() { o = new Object(); }
    public void testAdd() {
        LinkedList l = new LinkedList();
        l.add(o);
        assertTrue(l.contains(o));
    }
    public void testPushPop() {
        LinkedList l = new LinkedList();
        Object o2;
        l.addFirst(o);
        o2 = l.removeFirst();
        assertTrue(o==o2);
        assertTrue(l.size()==0);
    }
}

More Asserts

- Junit has several different tests
  - assertTrue(b) -- asserts that b is true
  - assertFalse(b) -- asserts that b is false
  - assertEquals(o1, o2) -- assert that o1.equals(o2)
  - assertNull(o) -- assert o != null
  - assertNotNull(o) -- assert o == null
  - assertSame(o1, o2) -- assert o1==o2
  - assertNotSame(o1, o2) -- assert o1 != o2
Manually Constructing a Test Suite

```java
public class ListTest extends TestCase {
    ...
    public static Test suite() {
        TestSuite suite = new TestSuite();
        suite.addTest(new ListTest() {
            protected void runTest() { testAdd(); }
        });
        suite.addTest(new ListTest() {
            protected void runTest() { testPushPop(); }
        });
        return suite;
    }
}
```

Manually Constructing a Suite (cont’d)

- You can also create test suites more easily:
  ```java
  public static Test suite() {
      TestSuite suite = new TestSuite();
      suite.addTest(new ListTest("testAdd");
      suite.addTest(new ListTest("testPushPop");
      return suite;
  }
  ```

- Or simply:
  ```java
  public static Test suite() {
      return new TestSuite(ListTest.class); }
  ```
Using a Test Suite

• Test runners will use static suite() method

• **If no suite() method, suite selected automatically**
  – Every method that is **public**, returns **void**, takes no arguments, and begins with “test”
  – This is the way to go – for project 2, use this style

• Then use junit.*.TestRunner TestClass
  – Or use DrJava