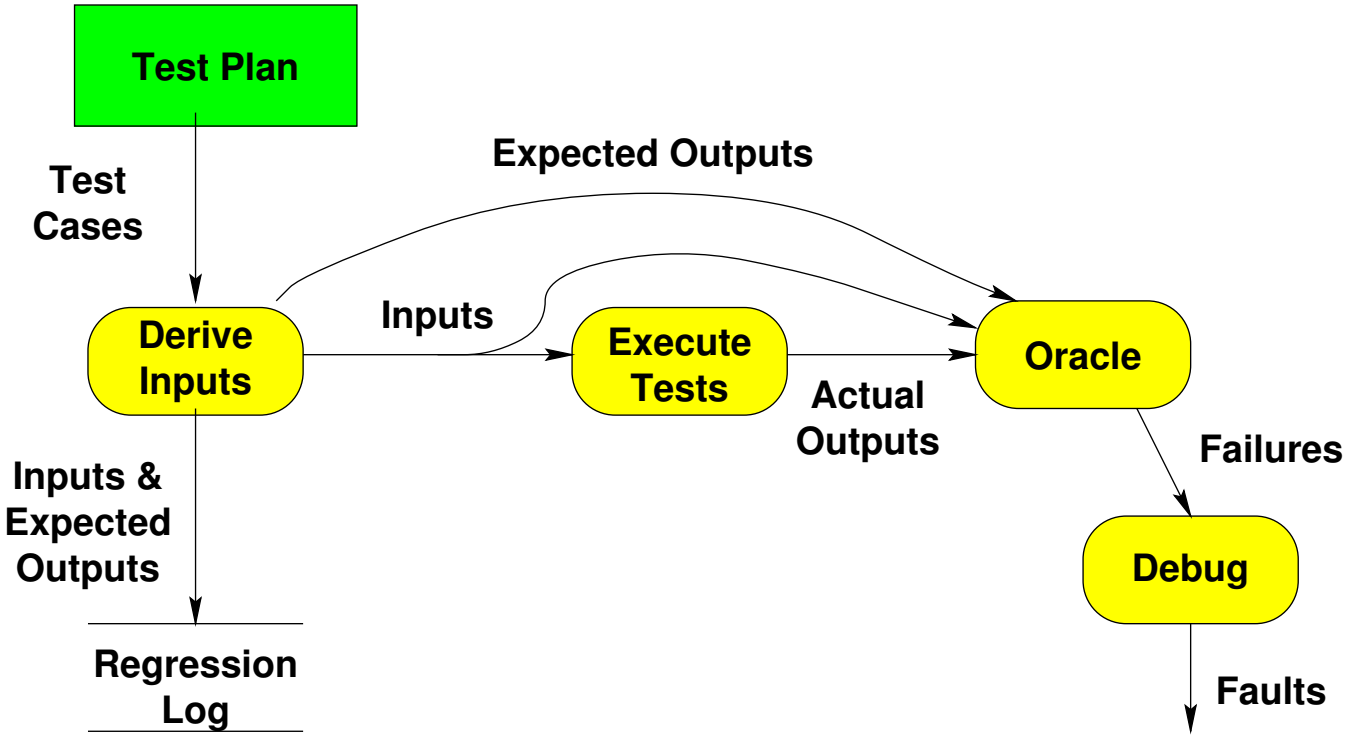
Automating the Testing Oracle

Steven J Zeil

February 13, 2013


Outline


The Testing Process



Earlier we introduced this model of the basic testing process.

- In this lesson, we turn our attention to the *oracle*


Outline I


Why Automate the Oracle?

- Most of the effort in large test suites is evaluating correctness of outputs
  - The *oracle* is a decision procedure for deciding whether the output of a particular test is correct.
  - Humans ("eyeball oracles") are notoriously unreliable
    - better to have tests check themselves.
  - Regression test suites can be huge.
- Modern development methods emphasize rapid, repeated unit tests
  - *Test-driven development*: Develop the tests *first*, then write the code.
  - Debugging: if you can't reproduce the error, how will you know when you've fixed it?

  But that's just not going to happen if testing is hard to do.


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests
- Databases


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests
- Databases
  - Clone and compare, or


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests
- Databases
  - Clone and compare, or
  - Use queries to search for changes


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests
- Databases
  - Clone and compare, or
  - Use queries to search for changes
- Graphics (screen) – difficult


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests
- Databases
  - Clone and compare, or
  - Use queries to search for changes
- Graphics (screen) – difficult
  - screen captures hard to compare, often too finicky


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests
- Databases
  - Clone and compare, or
  - Use queries to search for changes
- Graphics (screen) – difficult
  - screen captures hard to compare, often too finicky
  - design for testability


Output Capture

If we are doing systems/regression tests, the first step towards automation is to capture the output:
If output is to:

- Standard output: `diff` or `cmp` on standard output
  - Capture outputs for system-level regression tests
- Databases
  - Clone and compare, or
  - Use queries to search for changes
- Graphics (screen) – difficult
  - screen captures hard to compare, often too finicky
  - design for testability
    - capture "events" in a testing log


Output Capture and Drivers

At the unit and integration test level, we are testing functions and ADT member functions that most often produce data, not files, as their output. That data could be of any type.
How can we capture that output in a fashion that allows automated examination?

- Traditional answer is to rely on the *scaffolding* to emit output in text form.
- A more sophisticated answer, which we will explore later, it ro design these tests to be self-checking.

File tools

- **diff**, **cmp** and similar programs compare two text files byte by bute
  - used to compare expected and actual output
  - useful in *back-to-back* testing of
    - old system to its new replacement
    - system before and after a bug repair
    - but also used with manually generated expected output
  - parameters allow special treatments of blanks, empty lines, etc.
  - some versions can be used with binary files

Alternatives

- More sophisticated tests can be performed via **grep** and similar utilities
  - search file for data matching a regular expression


Custom oracles

- Some programs lend themselves to specific, customized oracles
  - For example, a program to invert a matrix can be checked by multiplying its input and output together — should yield the identity matrix.
- pipe output from program/driver directly into a custom evaluation program, e.g.,

```
testInvertMatrix matrix1.in > matrix1.out
multiplyCheck matrix1.in < matrix1.out
```

  or

```
testInvertMatrix matrix1.in | multiplyCheck matrix1.in
```

- Most useful when oracle can be written with considerably less effort than the program under test


Expect

expect is a shell for testing interactive programs.

- an extension of **TCL** (a portable shell script).


Key expect Commands

spawn Launch an interactive program.


Key expect Commands

spawn Launch an interactive program.

send Send a string to a spawned program, simulating input from a user.


Key expect Commands

spawn Launch an interactive program.

send Send a string to a spawned program, simulating input from a user.

expect Monitor the output from a spawned program. Expect takes a list of patterns and actions:

```
pattern1 {action1}
pattern2 {action2}
pattern3 {action3}
    ⋮        ⋮
```

and executes the first action whose pattern is matched.

Key expect Commands

spawn Launch an interactive program.

send Send a string to a spawned program, simulating input from a user.

expect Monitor the output from a spawned program. Expect takes a list of patterns and actions:

```
pattern1 {action1}
pattern2 {action2}
pattern3 {action3}
    ⋮        ⋮
```

and executes the first action whose pattern is matched.

interact Allow person running expect to interact with spawned program. Takes a similar list of patterns and actions.


Sample Expect Script

Log in to other machine and ignore "authenticity" warnings.

```
#!/usr/local/bin/expect
set timeout 60
spawn ssh $argv
while 1 {
  expect {

    eof                                {break}
    "The authenticity of host"         {send "yes\r"}
    "password:"                        {send "$password\r"}
    "$argv"                            {break} # assume machine na
  }
}
interact
close $spawn_id
```


Expect: Testing a program

```
    puts "in test0: $programdir/testsets\ n"
catch {
   spawn $programdir/testsets

   expect \
    "RESULT: 0" {fail "testsets"} \
    "missing expected element" {fail "testsets"} \
    "contains unexpected element" {fail "testsets"} \
    "does not match" {fail "testsets"} \
    "but not destroyed" {fail "testsets"} \
    {RESULT: 1} {pass "testsets"} \
    eof {fail "testsets"; puts "eof\ nl"} \
    timeout {fail "testsets"; puts "timeout\ n"}
}
catch {
    close
    wait
}
```


Structured Output

For unit/integration test, output is often a data structure

- Data must be *serialized* to generate text output and parsed to read the subsequent input


Structured Output

For unit/integration test, output is often a data structure

- Data must be *serialized* to generate text output and parsed to read the subsequent input
- A lot of work


Structured Output

For unit/integration test, output is often a data structure

- Data must be *serialized* to generate text output and parsed to read the subsequent input
- A lot of work
  - Easy to omit details


Structured Output

For unit/integration test, output is often a data structure

- Data must be *serialized* to generate text output and parsed to read the subsequent input
- A lot of work
  - Easy to omit details
  - Can introduce bugs of its own

Structured Output

For unit/integration test, output is often a data structure

- Data must be *serialized* to generate text output and parsed to read the subsequent input
- A lot of work
  - Easy to omit details
  - Can introduce bugs of its own
- Similar issues can exist with the need to supply structured inputs

Repository Output

For system and high-level unit/integration tests, output may be updates to a database or other repository.

- Must be indirectly "captured" via subsequent query/access


Repository Output

For system and high-level unit/integration tests, output may be updates to a database or other repository.

- Must be indirectly "captured" via subsequent query/access
- significant setup and cleanup effort per test


Repository Output

For system and high-level unit/integration tests, output may be updates to a database or other repository.

- Must be indirectly "captured" via subsequent query/access
- significant setup and cleanup effort per test
  - need separate test stores


Graphics Output

- For system and high-level unit/integration tests, output may be graphics
  - very hard to capture
- Similar issues can arise supplying GUI input
  - Supplying a repeatable sequence of input events (key presses, mouse movement & clicks, etc)
  - Sometimes timing-critical


Outline I


Self-Checking Unit and Integration Tests

- Addresses problem of capture-and-examine for structured data


Self-Checking Unit and Integration Tests

- Addresses problem of capture-and-examine for structured data
- Each test case is a function.


Self-Checking Unit and Integration Tests

- Addresses problem of capture-and-examine for structured data
- Each test case is a function.
  - That function constructs required inputs . . .


Self-Checking Unit and Integration Tests

- Addresses problem of capture-and-examine for structured data
- Each test case is a function.
  - That function constructs required inputs . . .
  - and passes those inputs to the module under test. . .


Self-Checking Unit and Integration Tests

- Addresses problem of capture-and-examine for structured data
- Each test case is a function.
  - That function constructs required inputs . . .
  - and passes those inputs to the module under test. . .
  - and examines the output. . .


Self-Checking Unit and Integration Tests

- Addresses problem of capture-and-examine for structured data
- Each test case is a function.
  - That function constructs required inputs . . .
  - and passes those inputs to the module under test. . .
  - and examines the output. . .
- . . . all within the memory space of the running function


First Cut at a Self-Checking Test

Suppose you were testing a *SetOfInteger* ADT and had to test the add function in isolation, you would need to know how the data was stored in the set and would have to write code to search that storage for a value that you had just added in your test. E.g.,

```
void testAdd (SetOfInteger aSet)
{
    aSet.add (23);
    bool found = false;
    for (int i = 0; i < aSet.numMembers && !found; ++i)
        found = (aSet[i] == 23);
    assert(found);
}
```


What's Good and Bad About This?

```
void testAdd (SetOfInteger aSet)
{
    aSet.add (23);
    bool found = false;
    for (int i = 0; i < aSet.numMembers && !found; ++i)
        found = (aSet.data[i] == 23);
    assert(found);
}
```

- Good: captures the notion that 23 should have been added to the set
- Good: requires no human evaluation
- Bad: relies on underlying data structure
  - Requires the tester to think at multiple levels of abstraction
  - Test is fragile: if implementation of SetOfInteger changes, test can become useless
  - Might not even compile - those data members are probably private


Better Idea: Test the Public Functions Against Each Other

On the other hand, if you are testing the add and the contains function, you could use the second function to check the results of the first:

```
void testAdd (SetOfInteger aSet)
{
  aSet.add (23);
  assert (aSet.contains(23));
}
```

- Simpler
- Robust: tests remain valid even if data structure changes
- Legal: Does not require access to private data


More Thorough Testing

```
void testAdd (SetOfInteger startingSet)
{
   SetOfInteger aSet = startingSet;
   aSet.add (23);
   assert (aSet.contains(23));
   if (startingSet.contains(23))
      assert (aSet.size() == startingSet.size());
   else
      assert (aSet.size() == startingSet.size() + 1);
}
```


More Tests

```
void testAdd (SetOfInteger aSet)
{
  for (int i = 0; i < 1000; ++i)
    {
     int x = rand() % 500;
     bool alreadyContained = aSet.contains(x);
     int oldSize = aSet.size();
     aSet.add (23);
     assert (aSet.contains(x));
     if (alreadyContained)
        assert (aSet.size() == oldSize);
     else
        assert (aSet.size() == oldSize + 1);
    }
}
```


assert() might not be quite what we want

Our use of `assert()` in these examples has mixed results

- Good: stays quiet as long as we are passing tests
  - failures easily detected by humans
- Bad: testing always stops at the first failure
  - In a large suite of many such test cases, we may be missing out on info that would be useful for debugging
- Bad: diagnostics are limited to file name and line number where the assertion failed.


Outline I


JUnit

JUnit is a testing framework that has seen wide adoption in the Java community and spawned numerous imitations for other programming languages.

- Introduces a structure for a


JUnit

JUnit is a testing framework that has seen wide adoption in the Java community and spawned numerous imitations for other programming languages.

- Introduces a structure for a
  - suite (separately executable program) of


JUnit

JUnit is a testing framework that has seen wide adoption in the Java community and spawned numerous imitations for other programming languages.

- Introduces a structure for a
  - suite (separately executable program) of
  - test cases (functions),


JUnit

JUnit is a testing framework that has seen wide adoption in the Java community and spawned numerous imitations for other programming languages.

- Introduces a structure for a
  - suite (separately executable program) of
  - test cases (functions),
  - each performing multiple self-checking tests (assertions)


JUnit

JUnit is a testing framework that has seen wide adoption in the Java community and spawned numerous imitations for other programming languages.

- Introduces a structure for a
  - suite (separately executable program) of
  - test cases (functions),
  - each performing multiple self-checking tests (assertions)
    - using a richer set of assertion operators


JUnit

JUnit is a testing framework that has seen wide adoption in the Java community and spawned numerous imitations for other programming languages.

- Introduces a structure for a
  - suite (separately executable program) of
  - test cases (functions),
  - each performing multiple self-checking tests (assertions)
    - using a richer set of assertion operators
- also provides support for setup, cleanup, report generation


JUnit

JUnit is a testing framework that has seen wide adoption in the Java community and spawned numerous imitations for other programming languages.

- Introduces a structure for a
  - suite (separately executable program) of
  - test cases (functions),
  - each performing multiple self-checking tests (assertions)
    - using a richer set of assertion operators
- also provides support for setup, cleanup, report generation
- readily integrated into IDEs

Getting Started: Eclipse & JUnit

Let's suppose we are building a mailing list application. the mailing list is a collection of contacts.

Contact.java (source)

MailingList.java (source)

- Set up an Eclipse project with these two files
  - Make sure that these compile successfully with no errors.
- In the Eclipse Build Path, add a library: JUnit,
  - Choose JUnit4 if given a choice of versions 3 or 4


A First Test Suite

Right-click on the project and select `New...JUnit Test Case`.

- Give it a name (e.g., TestMailingList)
  - in the same `mailinglist` package as the two classes
- For "Class under test", use the Browse button and select our MailingList class
- Click Next, then select the `MailingList()` and `addContact(...)` functions


A First Test Suite (cont.)

You'll get something like this:

```
package mailinglist;

import static org.junit.Assert.*;

import org.junit.Before;
import org.junit.Test;

public class TestMailingList {

        @Test
        public void testMailingList() {
                fail("Not yet implemented");
        }

        @Test
        public void testAddContact() {
                fail("Not yet implemented");
        }

}
```

Save this, and run it (right-click on the new file in the Package Explorer, and select `Run As...JUnit Test`

- You'll see what failed tests look like.
  - Try double-clicking on the failed cases and observe the effects on the source code listing and the Failure Trace


A First Test

Let's implement a test for the mailing list constructor.

```
/**
 * Create an empty mailing list
 *
 */
public MailingList() {
```

Glancing through the *MailingList* interface, what would we expect of an empty mailing list?

- the `size()` would be zero
- any contact we might search for would not be contained in the list


Testing the Constructor I

Change the `testMailingList` function to

```
@Test
public void testMailingList() {
    MailingList ml = new MailingList();  ❶
    assertFalse (ml.contains("Jones"));  ❷
    assertNull (ml.getContact("Smith"));
    assertEquals (0, ml.size());         ❸
}
```

- ❶ Before we can test any function, we have to invoke it
- ❷ Notice the tests using different variations on the idea of an assertion
  - `assert(...)` itself remains a language primitive - we don't use that but use these JUnit variations instead


Testing the Constructor II

- Use `assertTrue` instead of `assert`
- The JUnit versions don't shut down all testing the way the primitive `assert(...)` would do

- The first failed JUnit assertion shuts down the test case (function)

- ❸ The order of parameters in `assertEquals` is significant
  - expected value comes first


Running the Constructor Test

1. Run the test suite as before
   - It should succeed (`testAddContact` will still fail)
2. Change the "0" in the final test to "1". Run again, and observe the message in the Failure Trace.
3. Restore the "0". Change the first line to

   ```
   MailingList ml = null; // new MailingList();
   ```

   and run again.
   - Notice that a "test error" is marked differently than a "failed test"
4. Restore the first line


Testing addContact

Now let's add a test for addContact:
After adding a contact

- the `size()` should increase
- the contact name should be contained in the list
- we should be able to find the contact that we just added.


Testing addContact - first pass

Try this test (run it!)

```
@Test
public void testAddContact() {
    MailingList ml = new MailingList();
    Contact jones = new Contact("Jones",
                                "21 Penn. Ave.");
    ml.addContact (jones);
    assertTrue (ml.contains("Jones"));
    assertFalse (ml.contains("Smith"));
    assertEquals ("Jones", ml.getContact("Jones").getNam
    assertNull (ml.getContact("Smith"));
    assertEquals (1, ml.size());
}
```

It works. But it feels awfully limited.


A Diversion - Test Setup I

Before we try making that test more rigorous, let's look at how we can organize the set up of auxiliary data like our contacts:

```
Contact jones;

@Before
public void setUp() throws Exception {
    jones = new Contact("Jones", "21 Penn. Ave.");
}
  ⋮
@Test
 public void testAddContact() {
     MailingList ml = new MailingList();
     ml.addContact (jones);
        ⋮
```


Fixtures

- The class that contains the data shared among the tests in a suite is called a *fixture*.


Fixtures

- The class that contains the data shared among the tests in a suite is called a *fixture*.
- A function marked as "@Before" will be run before each of the test case functions.


Fixtures

- The class that contains the data shared among the tests in a suite is called a *fixture*.
- A function marked as "@Before" will be run before each of the test case functions.
  - Used to (re)initialize data used in multiple tests


Fixtures

- The class that contains the data shared among the tests in a suite is called a *fixture*.
- A function marked as "@Before" will be run before each of the test case functions.
  - Used to (re)initialize data used in multiple tests
- Why *every* time?


Fixtures

- The class that contains the data shared among the tests in a suite is called a *fixture*.
- A function marked as "@Before" will be run before each of the test case functions.
  - Used to (re)initialize data used in multiple tests
- Why *every* time?
  - Helps keep test cases independent


Fixtures

- The class that contains the data shared among the tests in a suite is called a *fixture*.
- A function marked as "@Before" will be run before each of the test case functions.
  - Used to (re)initialize data used in multiple tests
- Why *every* time?
  - Helps keep test cases independent
  - During debugging, it's common to select and run single test cases in isolation


Fixtures

- The class that contains the data shared among the tests in a suite is called a *fixture*.
- A function marked as "@Before" will be run before each of the test case functions.
  - Used to (re)initialize data used in multiple tests
- Why *every* time?
  - Helps keep test cases independent
  - During debugging, it's common to select and run single test cases in isolation
- Can do cleanup in a similar fashion with "@After"


Testing addContact - setup

```
Contact jones;
Contact baker;
Contact holmes;
Contact wolfe;
MailingList mlist;

@Before
public void setUp() throws Exception {
    jones = new Contact("Jones", "21 Penn. Ave.");
    baker = new Contact("Baker", "Drury Ln.");
    holmes = new Contact("Holmes",
                         "221B Baker St.");
    wolfe = new Contact("Wolfe",
                        "454 W. 35th St.");
    mlist = MailingList();
    mlist.addContact(baker);
    mlist.addContact (holmed);
```

Testing addContact - improved

```
@Test
public void testAddContact() {
    assertTrue (mlist.contains("Jones"));
    assertEquals ("Jones",
                  mlist.getContact("Jones").getName());
    assertEquals (4, ml.size());
}
```

Still seems a bit limited - we'll address that later.


Outline I


Google Test

Google Test, a.k.a. gtest, provides a similar *Unit environment for C++

- Download & follow instructions to prepare library
  - gtest will be added to your project as source code
  - easiest is to copy the files from `fused-src/gtest/` files into a subdirectory `gtest` within your project.
- For Eclipse support, add the Eclipse CDT C/C++ Tests Runner plugin


Example

This time, the C++ version of the mailing list.

1. Source code is here.
   - Unpack into a convenient directory.
2. With Eclipse create a C++ project in that directory.
3. Compile
4. Run the resulting executable as a local C++ application
5. Run as a *unit test:
   - Right-click on the binary executable, select "Run as. . . Run configurations".
   - Select C/C++ Unit, click "New" button
   - On the "C/C++ Testing" tab, select Tests Runner: Google Tests Runner
   - Click "Run"


Examining the ADT

mailinglist.h Should look familiar after the Java version


Examining the Tests I

MailingListTests.cpp

- Roughly similar to the JUnit tests

❶ The class provides a fixture where data can be shared among test cases
  - This is optional, but common

❷ Test cases are introduced with TEST_F
  - First argument identifies the suite (same as fixture name)
  - Second argument names the test case
  - The combination must be unique
  - Use TEST if you don't provide a fixture class

❸ The test cases feature assertions similar to those seen in JUnit
  - EXPECT assertions allow testing to continue after failure
  - ASSERT variations also exist that shut down testing on failure


Examining the Tests II

❹ Public members of the fixture class will be visible to all test cases

❺ and are assigned the values during `SetUp`, run before each test case

❻ You can see the fixture members used here


Boost UTF

Boost is a well-respected collection of libraries for C++.

- Many of the new library components of C++11 were distributed in Boost for "beta test".
- Other, more specialized libraries will remain separately distributed.
  - This include another popular *Unit framework for C++, the Boost Unit Test Framework (UTF).
- Basic principles are similar to Google Test
  - Also has some support for building trees of test suites.


Boost Test

- The UTF can be added as a single header `#include` or, for greater efficiency when dealing with multiple suites, compiled to form a static or dynamic library.
- Easiest to start wit hthe single header approach. Download and unpack the Boost library.
  - Add the Boost `include` directory to your C++ project's search path for system headers (`#include <...>`)
    - In Eclipse, this is Project... Properties... C/C++ General... Includes.
    - Be sure to add to C++ language, all configurations
- For Eclipse support, use the same Eclipse CDT C/C++ Tests Runner plugin


Example

This time, the C++ version of the mailing list.

1. Source code is here.
   - Unpack into a convenient directory.
2. With Eclipse create a C++ project in that directory.
   - Add path to Boost `include` directory
3. Compile
4. Run the resulting executable as a local C++ application
5. Run as a *unit test:
   - Right-click on the binary executable, select "Run as. . . Run configurations".
   - Select C/C++ Unit, click "New" button
   - On the "C/C++ Testing" tab, select Tests Runner: Boost Tests Runner
   - Click "Run"


Examining the Tests I

MailingListTests2.cpp

1. This names the suite.
2. The class provides a fixture where data can be shared among test cases
   - Optional, but common
   - Simpler in Boost than in Google
     - Can be any class.
     - Initialization is done in the class constructor instead of in a special function.
3. Test cases that don't need anything from a fixture are introduced with `BOOST_AUTO_TEST_CASE`
   - Argument names the test case
4. The assertions have different names but are similar in function and variety to JUnit and GTest
   - A full list is here.


Examining the Tests II

❺ Test cases that need a fixture are introduced with `BOOST_FIXTURE_TEST_CASE`

- Second argument identifies the fixture class
- Public members of the fixture class will be visible to